The Optics Of Photography: And Photographic Lenses (1892)

John Traill Taylor

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AND

PHOTOGRAPHIC LENSES

BY

J. TRAILL TAYLOR

Editor of 'The British Journal of Photography'; Editor of 'Hardwick's Photographic Chemistry'; late Editor of 'The Photographic Times' (New York); Member of Council of the Photographic Society of Great Britain; Honorary Member of the Camera Club, The Photographic Club, the London and Provincial Photographic Association, and the Edinburgh Photographic Society; President of the North London Photographic Society; Corresponding Member of the Imperial Polytechnic Society of Russia, &c., &c., &c.

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THIS WORK IS DEDICATED

(BY PERMISSION)

TO

Captain W. de W. Abney,

R.E., C.B., F.R.S., D.C.L., ETC.,

A VICE-PRESIDENT OF
THE PHOTOGRAPHIC SOCIETY OF GREAT BRITAIN,

WHOSE
VALUABLE AND EXHAUSTIVE
PHOTO-CHEMICAL EXPERIMENTS, DISCOVERIES, AND WRITINGS
HAVE LAID THE ART-SCIENCE OF PHOTOGRAPHY UNDER
A DEEP AND LASTING INDEBTEDNESS
TO HIM.

PREFACE.

THIS little treatise is not theoretical but practical, and it is not intended for the makers but the users of photographic lenses.

Some of it is already familiar to readers of *The British Journal of Photography* and its *Almanac*, and such portions are reproduced by the kind permission of the Proprietor; while other portions are collated from my contributions to the Society of Arts, *The Photographic Times*, the Camera Club, and various other London and Provincial Societies. There are, however, several chapters written expressly for this work, while in every case the other matter has been entirely revised or re-written and brought up to date.

If it be said that there are innumerable lenses in commerce which are not even mentioned by name in this volume, I reply that each maker has his idio-

syncrasy—he may vary the diameters, foci, and curves of his productions, and select special trade terms by which to distinguish them, but I have preferred in all cases to associate each class of lens with the name of its first inventor, and believe that no lens in use at the present day has been omitted.

It is in the hope that the work will prove useful to photographers—both professionals and amateurs—that it is issued.

J. TRAILL TAYLOR.

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THE OPTICS OF PHOTOGRAPHY

AND

PHOTOGRAPHIC LENSES

CHAPTER I.

WHAT CONSTITUTES PHOTOGRAPHIC OPTICS—NATURE AND PROPERTIES OF LIGHT.

PREVIOUS to speaking of the lenses employed in photography, or the principles which underlie their construction, it will be necessary to explain what we mean by the term, the Optics of Photography, as contradistinguished from the optics of any other science, such as those which involve the use of the microscope or telescope.

The chief distinction lies in this: that in photographic optics, not only must those rays which are transmitted directly through the lens, or the *axial* rays, as they are designated, be brought to a focus, but also those which pass obliquely, or in a direction other than axial. The principal lenses, or object-glass, of a telescope or micro-

scope will not give a sharp image if removed in even a slight degree from perfect squareness of position in relation to the line of light. Hence, the sharpness of image produced by even the finest telescope object-glass is confined to a very small space in the centre, the rest of the image being indistinct, owing to the inability of an objective of this class to form a sharp image of an object, the light from which is transmitted obliquely.

In photographic optics, on the other hand, the construction of the lens must be such as not only to give a sharp image of the object to which it is directed, but also of those which lie within a certain extent on either side of the centre. In proportion as a lens embraces objects situated at a considerable distance from the point to which it is directed, so does such lens become entitled to the designation of being a 'wide-angle' lens.

But, further, the chief end of any optical instrument, such as the telescope or microscope, formed for visual examination, has been attained when it is made to produce an image that is sharp when examined with the eye. But with a photographic lens something more is required. The corrections of the lens must recognise the absolute necessity of all the chemical rays being brought to a focus at the same spot as the visible rays, so that not only will the image appear sharp to the eye, but it will be equally sharp when, as the result of the action of the chemical rays, it is developed upon the photographic plate. Such coincidence of the visible and chemical focus does not exist either in the telescope or microscope, but only in the photographic lens.

The optics of photography, therefore, takes cognisance of rays transmitted obliquely as well as axially, and of bringing both the chemical and visual rays to a focus on the same plane.

This paves the way for a consideration of the principles upon which the various classes of lenses are constructed.

Concerning Light.—As a fitting introduction to the subject of lenses, it is necessary that an explanatory remark be made on light. Without entering upon this abstruse topic, it is enough for our present purpose to observe that the undulatory theory of light is now generally accepted. This assumes light to be a certain result of setting in motion the ether which pervades all space, and owing to that motion we see objects upon which such ether waves fall.

But the functions of light are not confined to rendering objects visible; they also include heating and chemical action, or *actinism*. These three properties of lighting, heating, and actinism may be very easily demonstrated by the following simple experiment: Cover up a south window by an opaque screen, allowing the sun's rays to be admitted only through a small aperture. Now intercept the rays thus admitted by a prism, so as to have them spread out upon a sheet of white paper, and observe the gorgeous spectacle these rays then present. The beam of white sunlight is decomposed into its primary constituents, as shown in the diagram (Fig. 1), in which B represents the aperture through which the beam of light is admitted;

and which beam, but for the interposition of the prism P, would, without deviating from its straight path, fall at W. But the prism bends the ray, and decomposes it

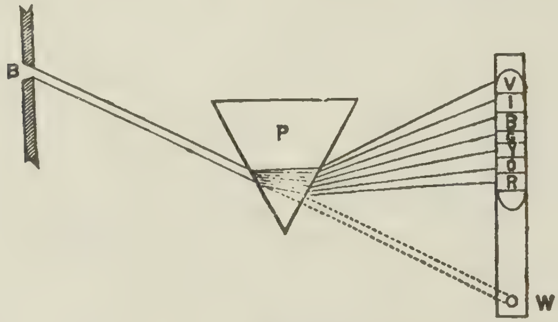

FIG. 1.

into the primary and secondary colours indicated by the initial letter of the spectrum, the violet ray V having been bent or refracted in a greater degree than the red ray R, from which circumstance the violet and blue rays of the spectrum are popularly spoken of as the visible rays of greatest refrangibility.

Demonstration of Properties of Coloured Light.—If a strip of sensitised paper be pinned up so as to receive the spectrum it will soon be found that it becomes dark; but the darkening power of the light is confined to the rays at and beyond the violet end. If, however, a thermometer be placed at the various colours of the spectrum, the mercury will rise in the most pronounced manner at, and even beyond, the red end; hence the application of the term 'heat rays' to these.

That the yellow is the luminous or light-giving ray is sufficiently demonstrated by the sense of sight. Now, while the foregoing is correct in the popular signification, it is also the case that all the rays induce chemical change, and it is possible to prepare a sensitive surface upon which the red rays will exercise more prompt action than the so-called actinic or violet light. But this need not here be considered.

We shall here sum up the truth or law to be deduced from what has been said. Light always travels in a straight line as long as the density of the transparent medium through which it is passing remains unchanged. Upon entering a denser medium obliquely it suffers refraction or bending, the amount of the refraction depending altogether upon the density of the medium. Pure water refracts more powerfully than air; water containing a salt—such as nitrate of silver—in solution exceeds pure water in its refractive power; crown glass exceeds salted water, and is in turn exceeded by flint glass, which last must yield the palm to the diamond and other gems. Suppose, then, we had four simple lenses, all precisely alike, so far as curvature and outward form were concerned, but one of them was formed by water encased by glass shells, the others being made of crown glass, flint glass, and diamond, respectively; each would have a different focus from the other, the water having the longest and the diamond the shortest.

Optical glass of greater density is being utilised at the present time much more extensively for photographic lenses than it was several years ago. One

practical advantage arising from this may be perceived from the principles just enunciated. It is this: that with a given diameter and form of lens it is possible to obtain a shorter focus, and, consequently, greater intensity of illumination than when the objective is formed of lighter material.

Pebble Lenses.—Transparent pebbles, such as the Brazilian topaz and other similar crystalline bodies of which spectacle glasses are sometimes formed, have in former times been strongly recommended as media for the construction of portrait lenses. Sir David Brewster advocated this on account of the greater softness obtained by a single lens of this nature than by an achromatic lens. But we now know that the softness desiderated arose from uncorrected aberration, and not from the material of which the lens was formed.

Aberration—What is it?—Seeing that throughout this work there will necessarily be much said concerning the aberration of lenses, it is well here to give such a general definition of the term as will embrace the ramifications afterwards to be specially treated under their proper headings.

Aberration merely denotes that deviation of the rays of light, when inflected by a lens, whereby they are prevented from meeting in the same point or geometrical focus. It is of a two-fold nature: (*a*) that arising from the figure of the glass, and (*b*) that caused by the unequal refrangibility of the rays of light. The former is 'spherical,' and the latter 'chromatic' aberration.

CHAPTER II.

PHOTOGRAPHIC DEFINITION, REAL AND IDEAL—FORMS OF SINGLE AND ACHROMATIC LENSES.

SHARP definition being an essential requisite in a photographic lens, we shall here make some observations on this quality, and try and assign a place to the well-defined photographic image. For reasons which will be adduced we are unable to give it a higher than a third place.

Ideal Definition. — Definition of the first order is ideal, existing only in imagination. It is that kind of definition which presupposes perfection in mathematical principles, in mechanics, and in atmospheric conditions. It is tolerant of things as they exist, merely because they cannot be helped. Optical transcendentalism, when indulged in by the photographer, demands a lens which shall define so perfectly that the application of unlimited magnifying power will only serve as a means of unlimited penetration into Nature's arcana; a lens having an aperture abnormally great in proportion to its focus, with a range of lateral definition so extensive as to include a panorama; and a penetrative depth sufficient to embrace everything from within a few feet to infinity. This is the ideal or hypothetic

lens. Optical conservatives say that such a lens cannot possibly exist save in the brain of some enthusiast; but recent progress made in Jena, in the production of glass having wonderful and valuable optical properties, warrant us in being very cautious in assigning a limit to the capabilities of any lenses yet *in futuro.* For its productions, however, when they come, we reserve the first place in our classification.

Telescopic Definition.—The second order of definition is that which we find existing in a well-constructed telescope or microscope. The image formed by their object-glasses is never examined by the unaided eye, but invariably through powerful magnifying glasses, technically known as 'eye-pieces,' or 'oculars.' This demands a perfection of definition altogether unknown and unrequired in artistic photography.

Photographic Definition.—Definition of the third order is of a lower grade than that just described. Photographic definition may be considered as fulfilling every requirement of our art-science, when not only is there no portion of the picture noticeably deficient in sharpness, even at its margin, but also when it bears the test of examination by a glass magnifying three or four times. There are many otherwise excellent lenses which will not permit of this last test being applied to their productions unless when used with a very small diaphragm, and it is sometimes desirable that one should have the power, both with single and combination objectives, of reproducing a scene or subject with less sharpness than that which it appears to possess to the eye of the

observer. The appliances for obtaining such effects will be considered in a subsequent chapter.

Refraction by Lenses.—We have seen in Fig. 1, Chapter I., in what manner a ray of light becomes decomposed when it is transmitted through a prism. Now, a lens may be considered a series of prisms formed by a single piece of glass, its faces being spherical instead of an unlimited number of flat surfaces. The property possessed by a wedge-shaped piece of glass of bending and decomposing a ray of light applies equally to the glass, whether it be purely prismatic or lenticular in form, and no single lens formed of one piece of glass can possibly bring the rays transmitted through it to one focus; for, as we have shown, the violet rays, being bent so much more strongly than the red and all the others, are brought to a focus nearer to the lens than these. This defect is entitled 'chromatic aberration,' from *chroma* (colour) and *aberro* (I wander from). Its nature is shown in the diagram, Fig. 2, which represents rays *a a*, incident upon a double-convex lens L. These

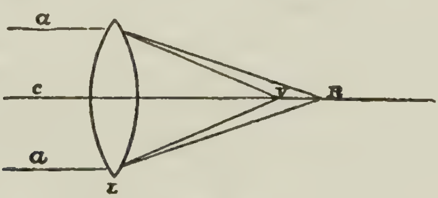

FIG. 2.

rays are not only bent or refracted but are also decomposed, which is what we have to do with at

present. The violet rays, in consequence of their greater refrangibility, are brought to a focus at V, the red rays finding a focus at R. By the term 'focus' is here meant that place where rays cross the axis *c* of the lens. This definition is only strictly accurate when applied to direct rays; a more comprehensive one will be given when we come to treat of oblique pencils.

Chromatic aberration is avoided by the employment of an achromatic (without colour) lens. The construction of an achromatic lens is based upon the fact that flint glass effects a much greater separation of the elementary colours of a ray of light than crown glass. A convex lens of the latter material would, undoubtedly, cause the rays to be decomposed, as shown in Fig. 2, but by being placed in juxtaposition with a concave lens formed of flint glass, the refracting power of which is exerted in a contrary direction while its power for dispersion is greater, the inward dispersive tendency of the crown is opposed by the outward dispersive proclivity of the flint, the result being that the ray is transmitted intact, or without colour, to its focus.

Forms of Single Lenses.—In Fig. 3 are shown, in outline, various forms of simple lenses, the names given having reference to the external configuration of the lens, no matter of how many elementary parts of other forms it may be composed.

In this diagram, 1 and 2 are respectively plano-convex and plano-concave lenses; 3 and 4 are double convex and double concave; 5 is a concavo-convex; and 6 a periscopic or meniscus lens. If 3 had one of

its surfaces of greater curvature than the other, it would be designated a 'crossed' lens.

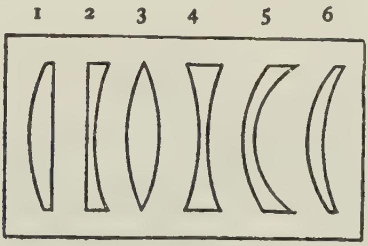

FIG. 3.

When lenses are achromatised by uniting a convex crown glass with a concave formed of flint glass, Fig. 4

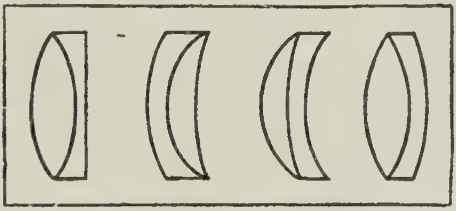

FIG. 4.

indicates some of the ways by which such union is effected.

Besides these, in which the achromatism is obtained by the union of one crown glass with one flint glass lens, the method (first applied to the telescope by John Dollond) of uniting two crowns with one flint has been advantageously applied to photographic lenses, details of which will be subsequently given.

CHAPTER III.

THE CAUSE OF AN INVERTED IMAGE.

HAVING spoken of the nature of lenses we next advert to their properties, particularly to that special characteristic upon which depends the formation of an image.

If a double convex lens formed of one piece of glass, such as a hand magnifier of the simplest kind, be held up so as to allow the sun's rays to be transmitted on to a sheet of paper held at a certain distance behind where the rays come to a point, the brightness at the apex of the cone is owing to the formation of a minute image of the sun there, its intensity either for luminousness or burning being dependent upon the dimensions of the lens. This applies also to the formation of an image of any terrestrial object to which the lens may in like manner be directed. In every case in which an image is produced in this way it will be seen to be inverted, or upside down. Why this is so we shall explain by the aid of the following diagram (Fig. 5), in which the dart A may be considered as representing anything in external nature, such as a church, a house, a landscape, or a figure. The rays of light from this pass in straight lines everywhere, and hence through the small hole B in the opaque sheet, which may be assumed to be the

front of a box. These proceed straight on until inter-

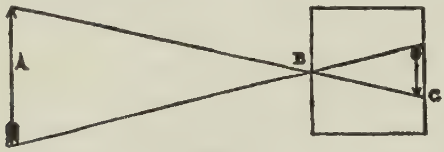

FIG. 5.

rupted by the screen C, on which they fall, forming an inverted image of the object in front.

Pinhole Apertures.—The smaller the aperture B is the sharper will be the image. It is, therefore, quite possible to take a photograph without any lens whatever; but, owing to the attenuation of the light by transmission through a pinhole aperture, a protracted exposure is required in order to obtain a picture. By greatly enlarging the aperture and inserting a lens, however, it will be found that, while the dimensions of the image formed by the pinhole aperture are not sensibly altered, there is at once a great increase in both the brightness and sharpness of such image. It may here be remarked that the size of the image is determined by the distance at which the receiving screen upon which the image is depicted is situated from the aperture or lens by which it is formed—a fact that will be self-evident on inspecting the foregoing diagram, and imagining the situation of the screen C to be only half the distance from the pinhole at which it is now represented.

Size of Image determined by Focus of Lens.—From what has been said it will be seen that the longer the

focus of a lens by which an image is to be formed the larger will be that image. If a lens of ten inches focus be employed in the production of a picture of a scene, such as a house and its surroundings, and another picture of the same scene be taken by a lens of five inches focus, when both are examined side by side it will be observed that the house produced by the lens of the shorter focus will only be one-half the dimensions of that obtained by the lens of longer focus; but, as a set-off against this, there will be twice as much of the subject depicted on a plate the same number of inches in dimension. From this it will be correctly inferred that a wide-angle lens—that is, a lens intended to include a wide angle or large amount of the subject to be photographed—must be of short focus relatively to other lenses. Another deduction from this is that dimension or size of image depends exclusively upon the focus of the lens, and is entirely unconnected with its diameter. If we have a lens of ten inches focus and only one inch diameter, and another lens the same focus and four inches in diameter, the images formed by them will be precisely alike in dimensions. The influence of the diameter of the lens is confined to giving greater or less brightness to the image, and we shall consider this more fully when treating of the requirements of quick-acting lenses.

CHAPTER IV.

SPHERICAL ABERRATION.

A SINGLE lens of the class of which we have been hitherto treating does not give an image possessing more than a very low degree of sharpness, even to the unaided eye. This arises from *spherical aberration*, which we may define as an inability in a lens having a spherical surface to bring to one focus all the rays which are transmitted through it. A ray transmitted by the margin of a lens (Fig. 6) is more deflected

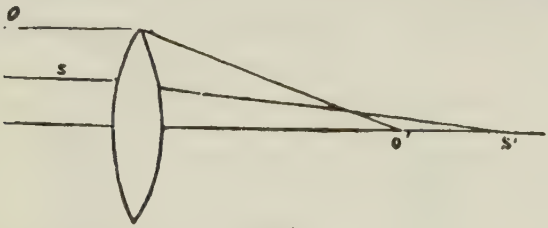

FIG. 6.

or refracted than one which is transmitted nearer the centre. Observe in what manner the representative rays O and S are refracted by the lens. The former, being bent in a greater degree than the latter, comes to a focus at O', the focus of S being carried farther to

S′; and the absolute focus of such a lens will be nowhere in particular, but anywhere between O′ and where the rays which are more nearly central cross the axial line. Now, this has no connexion whatever with the aberration of colour, but is true of a lens even if achromatised. It is possible to correct a single achromatic lens so that it shall with its full aperture bring direct rays to a focus, which is the case with telescope lenses; but for oblique rays it would be quite worthless. Photographic correction of lenses, therefore, partakes of the nature of a compromise; it is content with an inferior order of axial definition in order to secure an equal degree of oblique sharpness.

A plano-convex lens, or one of a slightly meniscus form, if directed, convex side out, to an object will give a fairly well-defined image of what is directly in front;

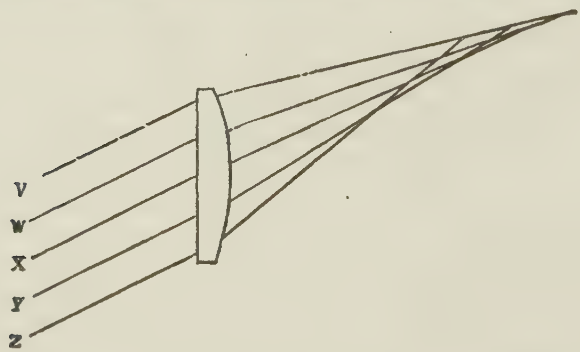

FIG. 7.

but those objects not axially situated will be very imperfectly rendered indeed. Now, by reversing the

position of the lens—that is, placing its flat side outwards—quite a different aspect is presented; for the central sharpness now gives place to a certain kind of indistinctness of image inferior in this respect to the former crispness of delineation; but this inferior distinctness is distributed over a larger area of the plate. The reason for this will be seen from an inspection of the diagram (Fig. 7), in which a few oblique rays are represented before and after transmission. It will be perceived that V and W suffer less refraction than Y and Z, and this being the case there is a great degree of confusion at the focus, which, as in the former instance adduced with the axial rays (Fig. 6), is really 'nowhere.'

Positive and Negative Spherical Aberration.—In the foregoing instances and illustrations, in which the margin of the lens refracts the light to a much greater extent than does its centre, the aberration is *positive*. But it is

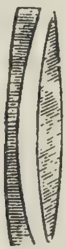

FIG. 8.

FIG. 9.

quite easy to combine two glasses, one a convex and the other a concave, with an air-space between them,

in which this condition will be reversed, or, to put it popularly, in which the centre of the compound will be possessed of a great magnifying power and the margin not necessarily any at all. The two illustrations here given (Fig. 8 and Fig. 9), in which the inner surfaces are of dissimilar radii of curvature, afford a fair idea of the conditions requisite to attain this end. This property is known as *negative* spherical aberration, and its use in flattening the field of certain combinations will hereafter be pointed out.

No single lens can be made that shall be entirely free from spherical aberration, but by giving a lens a certain form it may be very greatly reduced. If a lens be a plano-convex, and its flat side be directed towards the object, the aberration is 4·5; but if the position is reversed, and the convex side held toward the object, the aberration is reduced to 1·17.

The longitudinal aberration is ascertained by noting the difference between the focus given by the margin of a lens and that of its middle. While making this trial, opaque masks must be employed to prevent the transmission of light through any but the part being tested.

In a lecture on lenses at the Society of Arts, Mr. Conrad Beck gave 'in a nutshell' a synopsis of the aberrations of the various forms of lenses, both convex and concave. Premising that, as a general rule, when parallel rays enter from a less refracting medium (air) into a denser medium (glass), the more curved the surface that is turned towards the parallel rays the less is the aberration, while the flatter the curve or

the more nearly it approaches a flat surface the greater the aberration, the amount of such aberration is shown in the following figures, the parallel rays being assumed to enter each individual lens from the left-hand side.

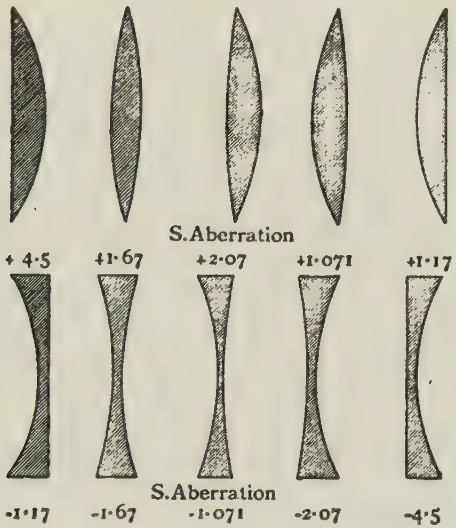

FIG. 10.

In the above, the upper or convex series are of the same focus as the lower or concave series, so that any one of the former will just balance that of the negative focus below. The amount of aberration, *plus* or *minus*, is placed underneath each. By comparing the figures attached to any of these lenses, even those of the same form, such as the first and last in upper series, it will be perceived to what extent aberration is affected according to the side which is turned towards the light.

CHAPTER V.

THE NATURE AND FUNCTION OF THE DIAPHRAGM OR STOP.

HOW, by whom, or at what time a diaphragm came to be designated a 'stop' we need not here wait to inquire. Photography has given rise to so many new terms and new applications of pre-existing terms that its literature, and especially its vernacular dicta, must not be considered as amenable to strict etymological rules. A diaphragm, in all other branches of optical science than that of photography, differs from a stop, but in our young art-science they are held by the *vox populi* to be synonymous; hence the indiscriminate employment of the two terms in what we have further to say in these chapters.

Use of a Diaphragm.—A diaphragm fulfils two altogether dissimilar functions in photography, according to whether the lens to which it is attached be a single or a compound instrument. In the former it is a necessity; in the latter only an expedient. It has been shown in what manner rays are transmitted by a single lens, and that those impinging upon one part of the surface are not brought to a focus with such rays as are permitted to fall upon another portion. Now, by placing a diaphragm at a little distance in front of the lens, it

cures all the evils arising from spherical aberration by debarring access to those rays which, if transmitted, would interfere with ultimate sharpness.

In Fig. 11 we show in what manner the 'curative'

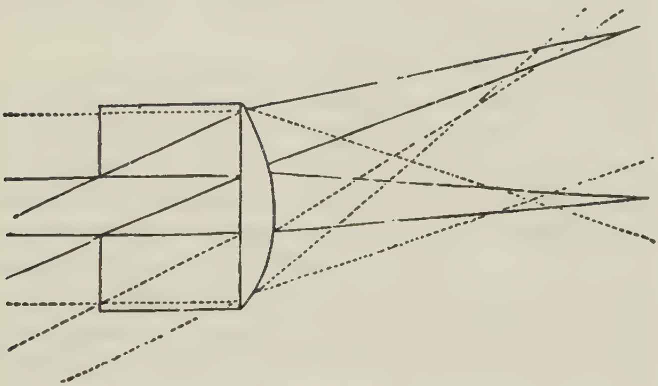

FIG. 11.

powers of the diaphragm are exercised when employed as a stop to obstructant rays, both central and oblique. Observe what havoc would be played as regards focal sharpness if the mass of the rays were permitted indiscriminate access to the lens. The dotted lines represent those by which definition would be entirely marred were they not stopped by the diaphragm, which, sentry-like, guards the access to the lens. What has, therefore, to be effected in this case by the diaphragm is this—no rays are allowed to take part in the formation of the central portion of the picture but those transmitted through the centre of the lens; and, in like manner,

none but rays transmitted through the margin of the lens are allowed to form any but the margin of the picture. This is the law regulating the margin of a diaphragm to a single achromatic lens, and from what has been said it will be seen that to a lens of this class the stop is a necessity.

Misconceptions Regarding Diaphragms.—Before proceeding further we may allude to a very prevalent and popular misconception, which finds expression in the suggestion that by making the lens of only the diameter of the largest diaphragm an equal degree of sharpness would be secured. While this is quite true as regards the formation of the centre of the picture—which would be equally well defined if an opaque disc of paper having a round hole in its centre were pasted upon the surface of the lens, and by which it would be practically reduced to the dimensions of the aperture in the paper—it is not so with the sides of the picture, which, although equally well lighted as before, are now badly defined. The following experiment is both suggestive and instructive: —Let a plano-convex or meniscus lens (the front lens of a portrait combination answers the purpose well) be mounted, flat side out, and without any diaphragm. Now try to focus the image, and observe that while no part of it is sharp, it is rather more so in the centre than towards the sides. Next make a cardboard diaphragm, with an aperture about one-fourth the diameter of the lens, push it close up against the flat surface, and then focus the centre as sharply as possible. This will now be well defined, but only over a very limited area,

Without altering the camera or lens pull the diaphragm slowly away from the lens, and it will be found that, by the simple act of increasing the space between the diaphragm and the lens, the area of sharpness extends outwards, till a point is reached at which further withdrawal of the diaphragm cuts off the light from the corners of the plate without further increasing the marginal definition. At this stage the requirement has been fulfilled that the centre of the picture be formed by the centre of the lens, and, in like manner, that no rays have taken part in the formation of the margins of the picture but those transmitted by the margin of the lens.

When applied to a combination of lenses—such as that employed in portraiture—the function of the diaphragm is different from that just described; for such

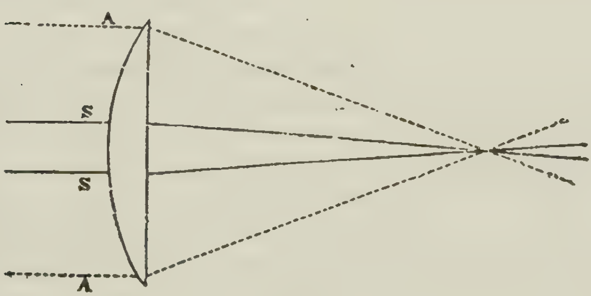

FIG. 12.

combination, being corrected in itself for spherical observation, gives a sharp image with its full aperture.

But it is characteristic of all portrait lenses and others having a large working aperture that they lack the power of bringing objects situated at different distances to a focus on one plane; or, as it is commonly said, they have no 'depth of focus.' By reducing the aperture a portrait lens can be made to possess as much of this depth of defining power as may be required. The way by which this is secured is shown in the diagram, Fig. 12, in which the dotted lines A A represent the rays transmitted through a lens worked with its full aperture. Observe that this focus partakes of the nature of a definite point, at which it is imperative that the ground glass of the camera be situated in order to obtain sharpness. Now this is all very well, and it is the easiest thing in the world to place the focussing-screen in that precise position. But here lies the difficulty: this spot of precise focus is that for rays only which come from a definite distance in front of the lens (say 12 feet), while those rays emitted by an object either ten or fourteen feet away do not focalise at the same point or distance behind the lens—one set of rays coming to a focus nearer and the other further than the twelve-feet set.

To meet the difficulty just stated we must have recourse to a diaphragm by which all rays outside of S S are excluded, with this result—that the point at which the rays crossed the axis of the lens has now *in effect* become elongated, and a fairly good focus is obtained without the necessity that formerly existed for having the ground glass situated in one definite position.

The reduction of the aperture has given such a range to the focus that, while the sharpness of the object originally focussed upon with full aperture remains unimpaired, this quality is now imparted to objects situated both nearer to and further from the camera.

No 'Depth of Focus' in Large Portrait Lenses.—For the reason just given a portrait lens of very large dimensions cannot be used with its full aperture in taking a head unless the sitter be placed a considerable distance from the instrument, because such is the lack of depth of definition in a lens of this character that if the nose were sharply focussed, the eye, ear, and other portions not situated upon the plane of the nose would be so much out of focus as to destroy the pictorial value of the head; while by focussing merely the eye, the nose and chin would be equally out. By employing a diaphragm, however, all the features may be brought into pictorial sharpness.

We may here foreshadow what we shall have to say afterwards in its proper place relative to the use of stops, by observing that a portrait or aplanatic lens (an *aplanatic* lens being one which is capable of working with full aperture) not only has its focal range, as regards depth, increased *ad libitum* by the employment of a diaphragm, but it has its lateral definition improved in similar ratio. A lens when worked with full aperture is unsuited for photographing anything requiring great marginal sharpness, such as copying a large sheet of printed matter or photographing a house on a plate otherwise within its capacity. By inserting a

diaphragm the range of sharpness will be so far extended as to enable the lens to execute work for which, without having recourse to this expedient, it would have been altogether unsuited.

Focussing with the Working Stop.—Unless a lens be quite free from spherical aberration, or, in other words, be aplanatic, it is well to focus with the same stop with which the picture is to be taken. There is often a great temptation to focus with a large diaphragm on account of the superior illumination of the image thus obtained, and then insert a small one. But with some lenses this ensures the very evil it is intended to avoid, for with a small stop the best point of focus is farther from the lens than when employing a large one. The reason for this will be apparent on studying the diagrams, Figs. 6 and 7.

For composing a picture, when one cannot have too much light upon the focussing screen, it may be well to employ the largest aperture possible; but when the subject has been arranged, then should the focussing be done as above indicated.

CHAPTER VI.

PROPERTIES OF DEEP MENISCUS LENSES—COMPENSATING SINGLE LENSES.

THE simpler the parts and structure of a photographic objective the less danger is to be apprehended from flare or false light caused by internal reflections. This being the case, why, it may be asked, not employ the simplest of all lenses—a single meniscus?

The Deep Meniscus.—A deep meniscus lens, whether single or achromatic, possesses properties different from all others. Those who desire to see the finest exemplification of the so-called 'depth of focus' possible to be obtained have only to procure a meniscus of very deep shape, expose its concave side to a bright object, and observe the image. This experiment may be performed by directing it to the flame of a candle situated at a distance of a few yards and receiving the image on a sheet of paper held in the hand. Having got the sharpest image that can be obtained, observe to what a great extent the lens may be moved backwards and forwards without the identity of the candle flame ceasing to be observed. It is true that it is surrounded with an aureola of false light, but the form itself is still there. In this respect it is quite unlike an image obtained by any other lens, such as a plano-convex, curved side out, in

which the slightest motion of the lens from its correct focal distance converts the image of the flame into a circular disc of light.

The spherical aberration by which the flare or mistiness of the image in the foregoing experiment is caused can be practically eliminated by the employment of a diaphragm; and here we may observe that photographs of great beauty and even sharpness may be, and often have been, taken by means of a simple non-achromatic meniscus lens. For a reason which will be apparent to those who carefully study the diagram, Fig. 2 (page 9), the photographic image will not be sharp unless care has been taken that, after focussing upon the ground glass, the lens is then pushed in towards the camera to such an extent as to cause the focus of the chemical or violet rays to take the place of the visual ones, which, as regards the ground glass, will now be quite out of focus. The difference between these foci is approximately one-thirtieth of the focus of a lens formed of crown glass; hence, if a ten-inch lens were employed it would, after focussing sharply, have to be pushed in over a quarter of an inch in order to secure a sharp image on the sensitive plate. Now, this would be of no consequence whatever if distant objects alone were to be photographed, because, the difference between the two foci being a constant one, the ground glass could easily be let deeper, or set farther forward, in its frame to effect the requisite compensation. But while the difference is a constant one with respect to proportion, it is not so as regards quantity; for upon focussing a near object the lens, as

every one knows, must be withdrawn farther from the focussing-screen in order to obtain a focus, and the quarter-of-an-inch alteration of the screen in the frame would prove totally inadequate when, in photographing an object on the scale of the original, the lens had to be twenty inches from the plate.

This would obviously demand an adjustment between the visual and the working focus of a measurement greatly exceeding that employed under the circumstances described. Among other reasons, the trouble necessitated in effecting this adjustment has operated to prevent photographers from making use of lenses other than those in which the actinic achromatism is effected in such a manner as to ensure a strict coincidence of the visual and chemical rays. But as, notwithstanding the drawback mentioned, there are several advantages alleged to be found in simple crown glass meniscus lenses — cheapness being one, and less loss of light another—it is fitting that we here give the means whereby an accurate adjustment can be made so as to ensure the requisite sharpness with such lenses when used in either a single or combined state.

Compensating Methods for Simple Lenses. — Proportional compasses and suitable markings upon the sliding mount will suggest themselves as one obvious method by which to effect the desired adjustment; but that to which we have long confined ourselves—invariably recommended as superior to all other methods, and which owes its inception to that profound mathematical optician, Mr. Robert H. Bow, C.E., of Edinburgh—is

one more practically perfect (as we have often proved it to be under many ramifications) that even its talented progenitor could easily have imagined it to be. A weak and thin convex lens—such as may be obtained from spectacle lens opticians—must be selected, its strength being such that, when added to the focal length of the operating lens, it will have the power of reducing the focus two per cent, or any other proportion found to be the proper amount of adjustment for a very distant object. As the focal length of this supplementary lens will be very great—say from forty-five to fifty times that of the camera lens—very little error will be caused by inserting it at the place of the stop instead of in contact with the working lens. It has, therefore, merely to be dropped in a suitable slit in the mount, like a Waterhouse diaphragm, where it remains till the focus is obtained, after which it is removed and the photograph taken without it. The simplicity and beauty of this system must approve itself to every one.

The rule for finding the focus of the lens that must be inserted as a stop (when focussing) to effect the correction of the working lens is this—f being the focal length of the required lens :—$f_{11}=\frac{f_1 + f}{f - f_1}$ or when $f=50$ and $f_1=49$, $f_{11}=49f=245$ inches. This rule will be found useful in another direction when we come to speak of over-corrected lenses ; for the means described for curing the annoyances arising from the use of non-achromatised lenses apply equally to those in which the achromatism for colour is carried further than is re-

quired for photographic working as to those in which it is not carried sufficiently far.

Deep Meniscus Lenses require Small Diaphragms.—A deep meniscus, whether achromatised or not, requires a small stop placed comparatively close to the lens. This permits of the transmission of a very oblique ray, the incidence of the ray being more normal than in the case of a flatter lens. For this reason all wide-angle lenses must partake of the external form of the deep meniscus, and the diaphragms must be placed near to the lens.

When single meniscus lenses are mounted in doublet form—that is, one lens in front of and the other behind the diaphragm — there is a help towards correction accomplished naturally in the case of oblique rays, the nature of which we may explain as follows : — Let a symmetrical or, by preference, a non-symmetrical doublet, of which the back element is shortest in focus, be imagined, its two elements being deeply curved crown-glass menisci. When an oblique ray impinges upon the anterior lens in such a manner as to enable it to be transmitted through a stop placed between both lenses, it undergoes decomposition, and its violet constituent, being more strongly refracted than the yellow, falls upon the surface of the posterior lens nearer its margin than does the yellow ray, which, as we have said, is less refrangible than the other. But the nearer to the centre of a lens that a ray falls for transmission, the less is it refracted ; or, on the contrary, the margin of a lens possesses the refractive power in a greater degree. The yellow and violet rays which, therefore, were separated

by the action of the front lens are, to some extent, made to reunite by the back lens, seeing that the violet falls under the influence of a portion of this back potent to cause it to reunite with the yellow, which, being less refrangible in itself, is also transmitted by a portion of the lens possessing less power for refracting.

Accommodating Elasticity of Focus. — The deep meniscus lends itself wonderfully to combinations intended to have an easy, accommodating elasticity of focus. A single achromatic, deep meniscus, which is properly corrected for actinic achromatism, may have wedded to it as a back combination a lens formed of a single crown-glass meniscus, which shall not only correct the distortion of figure necessarily caused by the former when used alone, but shall do so without much interference with its actinic correction. In other words, the achromatised front when used alone has its chemical and visual foci coincident; yet when a single, non-achromatic, crown-glass meniscus is added to this, although there is a diminishing of the focus to about one-half, the chemical and visual foci are still practically coincident as before.

A practical outcome of this fact is that, when a photographer has a lens of the achromatised, wide-angle, non-distorting class, which may not be of precisely the focus he desires, he may temporarily lay aside its posterior element and substitute for it a simple lens of another focus, by which he can arrive at almost any focal result required. Having determined upon the focus desiderated he must start with this fact as a basis

that no two lenses of only half that focus will enable him to obtain what he desires. An important factor in the calculation is the distance that must intervene between the two lenses forming a combination. Knowing the foci of the particular lenses about to be employed in the formation, temporary or otherwise, of a new objective, the combined focus of the pair may be ascertained by multiplying together the individual foci and dividing by the foci added together, subtracting from the divisor the distances apart at which the lenses are to be mounted.

It will be obvious that when a combination is very near the focus desired, that focus may be lengthened or shortened till the required power is obtained by slightly separating or bringing the lenses nearer together. The nearer they are together, the shorter the equivalent focus.

This question will be found treated with greater fulness in the chapter on 'The Adjustment of Dissimilar Lenses.'

CHAPTER VII.

THE OPTICAL CENTRE OF SINGLE LENSES.

PREVIOUS to the consideration of either the solar, the equivalent, or conjugate foci of lenses, it is necessary that we speak of the 'optical centre,' this being the point from which focal measurements must be made. Our remarks will, at first, have reference only to the optical centre of *a lens*, by which we mean just what is expressed by this name and not of an objective or combination of lenses, which is quite another matter; for, if one choose to be too nice with definitions, it is not difficult to show that a combination has not an optical centre at all, or, to put it more intelligibly, that any given combination may have its optical centre at several places, according to the circumstances under which it is being employed.

The situation of the optical centre (or *focal* centre, as it has by some been designated) of a lens is determined by its form. In some forms it is within, and in others outside, of the lens. In a double-convex it is in the middle, or equi-distant from both surfaces; in a crossed lens it is situated at a point between the middle and the more convex of the two surfaces; a plano-convex has its

optical centre on the curved surface; while in a meniscus it is outside altogether, its distance from the lens being determined by the degrees of curvature of the surfaces.

To find the Centre of a Single Lens.—The method for finding the optical centre of a lens is this:—Draw two parallel radial lines, one from the centre of each curvature, and both being oblique to the axis; then connect the points at which they touch the curved surface by a line which, in the case of a meniscus, must be prolonged till it meets the axis. The point at which this junction line touches the axis is the optical centre. We shall now illustrate this law by applying it to the case of three of the four lenses just named.

Centre of Double Convex Lens.—In Fig. 13 we have a double convex lens, the radii of curvatures of both surfaces being *a* and *a'*, the lines from which to the

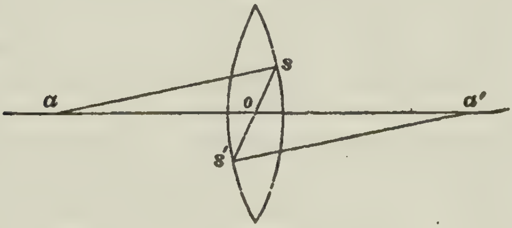

FIG. 13.

further surfaces in this and the two following figures are parallel to each other. From their points of impact on their respective surfaces, as *s s'*, a connecting line is drawn, and at the point *o*, where this line touches the axis, is situated the optical centre.

Centre of Crossed Lens.—By the flattening of one of the curves of the lens it becomes, as in Fig. 14, a crossed lens, having its optical centre at *o*, which in this case is not centrally situated.

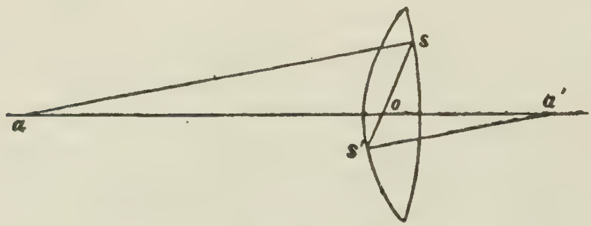

FIG. 14.

Centre of a Plano-Convex Lens.—This centre being situated on the convex surface of the lens, it is not necessary here to give an illustration.

Centre of Meniscus.—It is in the case of the deep meniscus now so much in use for many purposes, both singly and combined, where the greatest discrepancy exists between one's ordinary or crude conjectures as to the situation of the optical centre and its true position. In Fig. 15 it is demonstrated not only to be outside of the lens, but a long way outside. We have heard the question put to one who was reputed to be fairly conversant with optical matters: 'Where must I measure the focus of my lens from?'—the lens spoken of being a wide-angle, deep meniscus, having a stop in front. The response was: 'You will be sufficiently accurate by measuring from the centre of the curved surface of the lens.' Now, this reply is not correct

in the case of a lens of this form, although it would be so if one surface were plane instead of being concave.

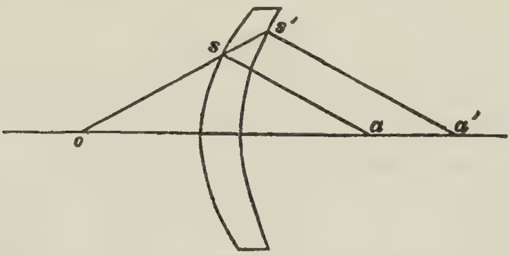

FIG. 15.

Properties of Optical Centre.—One of the properties of the optical centre of a lens is this—that any ray refracted by the lens which passes through this centre emerges in a direction parallel to that of its incidence. In most of the class-books on optics, the rule for finding the optical centre is expressed thus: 'Multiply the thickness of the lens by the radius of one surface and divide the product by the sum of the radii, and the quotient is the distance of the centre from the vertex of that surface.' The position of the centre is the same in every lens of the same dimensions, whatever may be the material of which it consists.

What has hitherto been said applies to single lenses, to which alone the term 'optical centre' is strictly applicable; and, although we have confined the illustrations to those of the positive or convex class, the rules equally apply to concave lenses.

CHAPTER VIII.

THE OPTICAL OR FOCAL CENTRE OF A COMBINATION.

In a *combination* of lenses, whether symmetrical or non-symmetrical, there is no fixed point which can be termed the 'optical centre.' The mistake, however, is frequently made of assigning it a position where the stop is placed. But the best position for the stop has not necessarily any relation to that of the centre, which can only have its position determined upon knowing the precise circumstances under which the combination is to be used, for it has strict relation to the conjugate foci. If these were so definitely fixed as to be invariable, then the position of the centre could be definitely allocated, but not otherwise; for every alteration of focus would be attended with a displacement of the central point. What is commonly termed the 'optical centre' in a combination is in reality the centre of conjugate foci, and this is determined by the conjugates, which, as already said, are changed with nearly every change of picture taken.

How to find the Focal Centre.—The place of the centre in a combination of any nature or form may be easily found, and for *any special purpose* it may be marked upon the brasswork of the mounting. The method

now to be described is one which involves no special apparatus. Suppose the lens to be a large portrait combination, and it is desired to know its centre when employed in portraiture. Let us assume the anterior conjugate (the sitter) to be at an average distance of (say) eighteen feet from the camera, then let the lens be brought into a darkened room and placed upon a board on the table. On this board must be laid a small square block of wood about two inches in height, and the upper surface of which is brought to a wedge shape. Now rest the lens across the face of the wedge, and let it be directed to a lighted candle placed in front at a distance equal to that at which the sitter is expected to be placed, and having erected, a few inches behind the lens, a white sheet of cardboard on which to receive the image of the candle, hold the lens (the weight of which rests upon the wedge-shaped block) level by the forefinger of the left hand, and with the right hand rotate the lens gently on the extemporised rotary axis formed by the wedge below and the finger above. Now observe if the image of the candle flame stand perfectly motionless, or whether, as will most likely be the case, it moves across the card with every rotation of the lens. In this latter case, move the lens a little farther backwards or forwards on the supporting block and try again. Do this until that position is found at which the image of the candle remains motionless while the lens is being rotated from side to side, and then put a small mark on the tube, which ever afterwards will indicate, with the degree of accuracy practically required,

the optical centre of the combination, whenever employed under circumstances in which the position of the conjugates assimilates to those under which the trial was made.

But to prove that the centre in question is really only that of these conjugates: after having made the mark on the tube, let the candle be brought to within six feet of the lens, and by another course of experiments let its centre be again found, and it will be seen that it now differs materially in position from that of the previous trial. The new centre is quite right for, and under, the altered conditions, but wrong as regards all others.

We are aware of some gentlemen who are so dexterous in examining a combination for its optical centre (we are now using the term under a kind of protest) that they will take it up and, poising it between finger and thumb, examine the stability of the image on the wall opposite a window while rotating the lens, and in this way will in less than half a minute have acquired more knowledge concerning it than another would in some days.

The Mechanical Centre not the Focal Centre.—To demonstrate that the focal centre is not situated in the mechanical centre, let us take the case of a combination of the cemented doublet class so commonly used, and let us further assume that it is a symmetrical compound, that is, that its front and back lenses are identical in figure and focus. Now while the mechanical centre of such a combination is midway between the lenses, the

focal centre may be anywhere according to circumstances. This will be readily understood from the following considerations: To adduce an extreme instance, let each lens of the combination be twenty inches in focus. These, if placed so close together as to be merged into one, and that one infinitesimally thin, would have a focus of ten inches, and its *focal* centre would measure from that of the lens. But in proportion as they are separated so does the focal centre move forward in advance of the mechanical centre; until at last when our hypothetic mount is nineteen inches long and the back lens is within an inch of the ground glass, the front lens being over nineteen inches away, where, under such conditions, would be the optical or focal centre for a distant object? It would be in the vicinity of the front lens and many inches in front of the mechanical centre.

The focal centre, or point from which the focus must be measured, varies therefore according to the distance of the object in front or its anterior or major conjugate.

CHAPTER IX.

SINGLE ACHROMATIC LENSES.

Historical Memoranda.—When photography was young, various devices to work with a large aperture, and at the same time to secure sharp definition, were had recourse to. It had been early found that simple lenses would not answer because of their actinic plane of representation being situated nearer to the lens than that of the visual focus; accordingly the single lens of the camera obscura was supplanted by the achromatic lens of the telescope, the surface of maximum convexity being placed to the outside. Owing to the circumscribed area of definition, the lens was afterwards reversed as regards position, and a diaphragm placed in front. The value of Wollaston's meniscus lens was in time duly recognised as a means of securing an extended field; and we find in a manual by Daguerre, published in 1839, a single meniscus achromatic, which is practically that manufactured at the present time, subject in some cases to modifications of internal curvature, in others to none.

Diaphragms Necessary with Landscape Lenses. — Single achromatic landscape lenses are usually either of plano-convex or meniscus form, and this latter is the more

pronounced according to the width of the angle of view it is intended to include. The deeper is its meniscus shape the smaller must be the stop, and the nearer must that stop be to the lens. If a single lens be intended to include only a very narrow angle, then may it be a crossed one, that is, both sides may be convex, the relation of the radii of the surfaces not being arbitrary, although approximately as one to six, the flatter side being outside or next the stop. We examined an old lens of this form, constructed by Goddard, and found, as might have been deduced *a priori*, that it bore a diaphragm unusually large, and placed at a considerable distance in front, but that its covering power was not great.

It is absolutely necessary that to ensure the best definition, a landscape lens must have a diaphragm, for in this respect it differs from combinations which may be made aplanatic. The reason for this is shown in Fig. 11, page 21. But this lens lends itself admirably to those who desire definition of a low order, to secure which, all that is necessary is to use it either without any stop at all, or with one much wider than the fixed diaphragm which the optician places in the mount.

Forms of Landscape Lenses. — In Fig. 16 we give the earliest form of landscape lens (that referred to in Daguerre's manual), and, as stated, it is much employed at the present time. It consists of a bi-convex crown cemented to a bi-concave flint. It is also modified by being externally a plano-convex, the flint glass lens in this case being plano-concave.

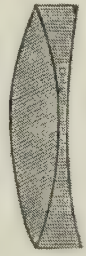

FIG. 16.

Grubb's Aplanatic. — The first departure from the above form was made in 1857, by Thomas Grubb, who reversed the relative positions of the flint and crown, as shown by Fig. 17, in which the lens, meniscus externally, is formed of a convavo-convex flint cemented to a meniscus crown. This lens was found to bear a larger working aperture than the one previously mentioned and to have less spherical aberration, hence his selection for it of the name 'Aplanatic.'

FIG. 17.

Dallmeyer's Wide-Angle Landscape Lens. — In 1865, J. H. Dallmeyer introduced a modification of the Grubb aplanatic, shown in Fig. 18. In this he divided the power of the crown glass into two, one placed in front and the other behind the flint glass. In this way, by sandwiching the flint concave, which was soft, between the two hard crown-glass menisci, the twofold purpose was attained of securing the softer glass from abrasion and of effecting better correction, for he was not confined to making both the crown elements of glass of similar refractive power. A subsequent modification of this lens has been made by T. R. Dallmeyer, who, while adhering to the same arrangement and configuration has, by the adoption of other kinds of glass than that employed by his father, adapted it for working with a larger aperture than was formerly employed.

FIG. 18.

An American Landscape Lens.—A lens achromatised in the same way as the 'Globe' has been employed as

a single landscape combination. As shown in the figure (Fig. 19) it consists of a concavo-convex flint and a meniscus crown, its components being placed so that the concave surface of the flint is outside. From the fact that this class of objective is very seldom to be met with, the inference may be deduced that it is inferior in general utility to the others previously described.

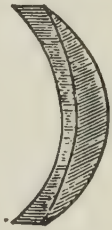

FIG. 19.

When, for the purpose of more effective correction, the inner or contact curves of a lens are of short radius, a considerable gain in thickness is obtained by grinding the margin of the concave surface flat, as in Fig. 20. By comparing this with the previous lens, it will be seen to what extent a gain is effected. With contact surfaces of the same radius carried out to the extreme edge, the lens would be abnormally thick. The flattened portion is of course protected by opaque varnish and a metal annulus. The light being transmitted from a diaphragm rather close to the concave surface, no loss is sustained by the smaller dimensions of the less dense positive element. The drawing is one of a wide-angle combination formed of light and heavy flint glass, instead of crown and flint.

FIG. 20.

Landscape Lens Mounting.—By whichever method a single landscape lens is corrected, it must be mounted with the stop next to its flatter side, as indicated in

Fig. 21, which represents one of the best forms of wide-angle lenses.

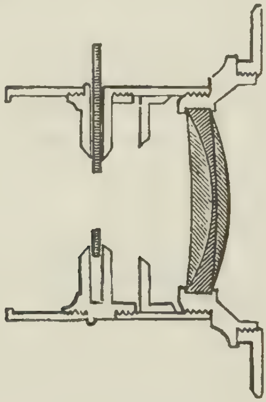

FIG. 21.

Non-distorting Landscape Lenses.—It was long held to be impossible for a lens of the single genus, having a diaphragm in front, to give a rectilinear picture; but, in 1859, the late James T. Goddard, under the title of the double periscopic lens, made several which, however, never came into general use. This lens, externally, was a double convex, and all the parts were cemented together in such a manner as to afford no clue as to its internal figuration. One of these which soon afterwards fell into our hands was dissected by placing it in warm water and undoing the bottom. It was then found that the interior portion of the lens was a double convex crown lens cemented to a double concave flint, the two neutralising each other in respect to magnifying power,

and that the back element was a meniscus of rather deep curvature and formed of crown glass. This lens was mounted with a stop in front of it. It will be seen from this description that there was a considerable air space between the back lens and the cemented portion.

Dallmeyer's Rectilinear Landscape Lens.—In 1887, T. R. Dallmeyer introduced a lens which, as implied by its name, gave freedom from distortion. In it he makes a species of compromise between the purely landscape lens and the rectilinear combination, and he effects this by displacing one of the crown elements of his triple landscape objective and transferring it in a reversed position to the opposite side of its *confrères*. It is known to those who have studied this landscape lens, that when one of its crown elements is removed. a flint negative and crown positive still remain, in which there is little or no power either for magnifying or diminishing. It is, however, a powerful corrector of the aberration of the third element. In Dallmeyer's new lens, he makes as it were a separate element of these two glasses and turns the convex surface towards the diaphragm, while immediately behind, he places the crown meniscus, by which the focus is determined. As the concave surfaces of both are next each other, there is thus an air-space left between them. Although this lens possesses some general features in common with Goddard, it cannot, in any sense, be considered to be a copy of his, because, in the first place, the only Goddard lens, the existence of which we can learn, has never been out of our own possession since it was made, and secondly, that Dall-

meyer's lens has a totally different internal construction which, we may add, gives it great advantages in covering power with better definition.

Advantages of Single Lenses.—Single lenses possess an advantage over double ones in respect to the pluck and vigour which they yield, a landscape being the subject. Being formerly constructed with only small diaphragms, they were necessarily slow in action, but this drawback has now been surmounted, some of the better class working with an aperture of even *f*-8. With an aperture of this width it need scarcely be said portraits can be easily obtained; indeed, for portraiture, there is a special charm in this class of lens, on account of the delicate softness which can be obtained when working with an abnormally great angular aperture. Of course, to cover an extended field sharply, a small stop must be employed, and as we have shown in another chapter the stop in the lens must be so placed as not to give a flare-spot.

CHAPTER X.

DISTORTION: ITS NATURE AND CURE.

THERE are several kinds of distortion capable of being produced in photography. These include that of 'violent perspective,' caused by placing the camera too close to the object to be taken, whether portrait, landscape, or building.

Point of Sight too Near.—This kind of distortion is seen in portraits in which the feet or hands are projected forward and represented on a scale of magnitude greatly surpassing that of the figure itself. The remedy for this consists in removing the camera to such a distance from the object as to reduce all the parts practically to the same uniform scale of representation. The employment of lenses of too short a focus has much to answer for in the production of this distortion of perspective. In these cases the perspective itself is not necessarily false—it is only violent; but it conveys an erroneous idea. In landscapes it causes insignificant ponds in the foreground to become considerable lakes, and tiny rivulets to assume the magnitude of rivers.

Distortion of Convergence.—There is also a very common form of distortion exemplified in the contraction of the

scale of representation towards one margin of the picture. It is usually seen in photographs of buildings, and gives them an appearance as if they were leaning towards an imaginary central line for support. This may be termed the 'distortion of convergence.' It arises from no fault in the lens, but from the want of care or of knowledge in the photographer, who, desirous of including the whole of a building in his plate, has tilted his camera slightly upwards without utilising its swing-back to bring the plate into a perfectly vertical state; for one of the rigid conditions which govern the taking of a building properly is this—that, no matter how much the lens or camera may be pointed upwards, the plate itself must be perfectly vertical.

Curvature of Straight Lines.—There are other kinds of distortion, but none that is justly chargeable to the lens save that very important one known as 'curvilinear distortion,' the chief characteristic of which is the curvature imparted in the photograph to lines that are quite straight in the original. This defect is produced solely by the lens, and no skill in the photographer can obviate it so long as a lens of that description is employed.

Every ordinary objective having its stop between the lens itself and the subject to be reproduced will give distortion. No matter how perfect a landscape lens may be—how superb its definition or penetrative its range; though it may reproduce the finest line of the finest engraving with all the crispness of the original and delineate the very structure of the stones of which an edifice is formed, yet it will not be either a copying

or an architectural lens. These demand not only all the qualities mentioned but also something more, namely, absolute rectilinearity in projection. The appearance presented in a photograph taken with a landscape lens in which a building is made to cover nearly the entire plate suggests the form of a huge, wide barrel, owing to all the straight lines curving inwards towards the centre. In such a picture only two lines are quite straight—those which pass vertically and horizontally through the centre of the photograph. No matter how much the lens distorts, these centre lines are always straight; but, in proportion as we proceed towards the margin, we find them becoming more and more curved. As this defect is not much noticed near the centre, it follows that one may take a view of a house or church without any apparent distortion so long as its position is kept near the centre of the plate; but for copying a map, chart, or any kind of engraving in which accuracy is a *sine quâ non*, it is altogether unsuitable.

Cause of Distortion.—Having indicated the nature, we shall now consider the cause of distortion. Bearing in mind what has been said in a previous chapter concerning the possibility of taking a photograph without any lens whatever, merely by transmitting the rays from the object through a pinhole aperture in front of the camera, we remark that any copy of a picture or representation of a natural object made by such pinhole will be quite rectilinear, for with such an arrangement the light passes in straight lines without refraction. Let us consider in what manner these rays are influenced

by a lens so as to disturb rectilinearity of projection. It has been shown that the margin of a lens refracts in a greater degree than its centre; that, in short, one of a set of parallel incident rays is transmitted through the centre of a lens without undergoing any refraction at all, and that in proportion as the point of transmission is near the margin or towards the centre so does the ray thus transmitted become refracted in a greater or lesser degree. All rays which come from a perfectly square map or building are quite right while passing through the diaphragm and up to their passage through the lens, when they are brought under the influence of its dimensions, with the result already described. The square original becomes barrel-shaped in the photograph, as shown in Fig. 22, in which the

FIG. 22.

curvature is, in order to show the principle, more pronounced than it would be with an ordinary photographic lens, because as the margin of a picture is taken with the margin of the lens, that margin, owing to its superior refractive power 'condenses' the rays into a smaller space or bends them towards its axis, thus causing a given portion of the original to occupy a smaller space near the margin than it would do at the centre of the photograph.

This is the invariable result of employing a lens, such as a single landscape objective, in which the stop is in front. What, it might be inquired, would be the result if the objective were turned round so as to allow the light to pass through the lens before it reached the diaphragm? Simply this: that the nature of the distortion would be changed. There would be an expansion of the scale at the margin instead of a reduction as in the former case, and the resulting picture would have its marginal lines bent outwards like a pincushion, as shown in Fig. 23, from which has arisen the term 'pincushion'

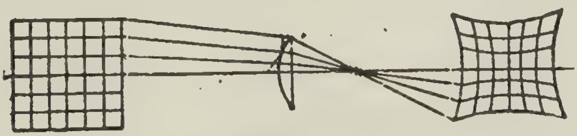

FIG. 23.

distortion, now recognised as the antithesis to the 'barrel' distortion already described.

The nature and cause of distortion having been explained with all the fulness required in a popular disquisition like the present, we now come to speak of the various methods adopted for effecting its cure. During a long period it was the earnest aspiration of both opticians and photographers to obtain a lens which would give freedom from distortion, and here in this connexion we would record one of the most remarkable things in optical history. While opticians were straining to devise a lens which should give freedom from distortion, it was already in their hands, although seemingly

they knew it not. So long ago as 1844, Geo. S. Cundell had published in the October number of the *Philosophical Magazine* of that year a symmetrical combination of lenses of form similar to the rapid rectilinear class of the present period, being meniscus lenses, although uncorrected, with a diaphragm midway between the lenses. How opticians failed to recognise in this combination the panacea for the evils of distortion is truly surprising. Cundell's lens, which was apparently entirely lost sight of by opticians, having been achromatised, is now *the* lens of the day. And here, as a sequel to the immediately foregoing illustrations of the two kinds of distortion produced by single lenses, we show in what manner the combination referred to cures distortion (Fig. 24). It

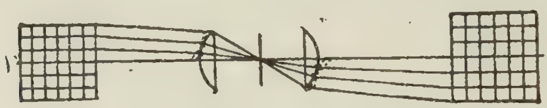

FIG. 24.

eventually began to dawn upon those people who gave thought to the matter, that if a diaphragm placed in front of a lens gave barrel-shaped distortion, and a diaphragm behind the lens gave distortion of the opposite or pincushion character, a diaphragm placed midway between two lenses would give no distortion at all. And so it was.

But at a date three years anterior to the publication of the Cundell lens, the late Andrew Ross had constructed for Henry Collen a portrait-objective, composed

of two plano-convex achromatic lenses with a stop midway between, and during the subsequent years of the life of this optician it does not appear to have occurred to him (as it did twenty-three years afterwards to his son, Thomas Ross), that this form satisfied the conditions of freedom from distortion, and that it was only necessary to make its components of a meniscus, instead of a plano-convex form, to flatten its originally round field.

Contemporaneous with Andrew Ross was Thomas Davidson, an Edinburgh optician, who produced some symmetrical achromatic lenses which were quite free from distortion, which will be described in another chapter.

The Condition for ensuring Non-distortion.—The condition that must be fulfilled by any combination of lenses in order that there shall be no distortion, is this—each ray that enters the combination must emerge from it in a direction parallel to that of its entry. If the immergent ray makes a certain angle with the axis of the lens, the emergent one must make a similar angle.

Advent of the Orthoscopic Lens.—The cry for non-distorting lenses was at its loudest, and all those just described had been forgotten or ignored when, in the beginning of 1857, Voigtlander introduced his orthoscopic lens, which was constructed on a formula supplied by Petzval. The orthoscopic lens became the 'rage.'

Several claims were put forward on behalf of this lens, and Thomas Sutton, editor of *Photographic Notes*, who was a facile writer on mathematical optics, descanted

in the most rapturous terms upon its numerous virtues —its entire freedom from distortion, flatness of field, equality of illumination, perfection of focus, and freedom from spherical aberration. The orthoscopic lens was to prove the panacea for every ill. It was everywhere spoken of; and, having become the fashion, there were some weak-minded photographers who scarcely dared venture to assert that any specially fine picture they had taken had perchance been obtained by the aid of the old-fashioned landscape lens. But fashions change in lenses as in other things, and subsequently it was found that the once-idolised orthoscopic lens did *not* possess freedom from distortion, that its field was *not* flat; that in equality of illumination and perfection of focus it was not a whit better than the old landscape lens. And so the orthoscopic lens was deposed from its position of reigning favourite and well-nigh lost sight of. What is to be regretted is that the foolish claim implied in its name was ever put forth, because any careful observer could upon close examination have discovered that it did distort, although from the position of the diaphragm the distortion was of an opposite character to that previously experienced.

In a subsequent description of lenses we shall not be disposed to treat the orthoscopic objective as defunct, because, when the absurd claim made for it upon its introduction has been set aside, it possesses special features and virtues of a marked order which may eventually secure for this instrument a recognition and patronage, doubtless, greatly exceeding that first accorded

to it. In saying this we are fortified by the expression of opinion of one of the ablest mathematical and practical opticians of the present time, to the effect that in the orthoscopic lens, when subjected to certain modifications of structure, may yet, possibly, be found one of the 'lenses of the future.'

A word in passing concerning the name 'orthoscopic' or 'orthographic'—signifying respectively correct seeing or correct delineating. It is much more applicable to the doublet lenses of the present time, which are really rectilinear (a term having an analogous meaning), than to that form about which we have been writing. We are rather pleased than otherwise to find that an American optician has lately re-adapted the name to a lens of the rectilinear class which he makes.

CHAPTER XI.

NON-DISTORTING LENSES.

THE nature of distortion having been fully treated in a previous chapter, we now enter upon a consideration of the various lenses which have been constructed with a special view to freedom from this error.

The Orthoscopic Lens.—We have already alluded to this as having been the first objective presented to the public with a direct claim to correctness in linear projection, although such claim was subsequently abandoned. The following is a description of it: It consists of a plano-convex or nearly flat achromatic meniscus, similar to the front lens of the Petzval portrait combination, and used in the same position. At a very short distance behind this is placed an achromatic lens, somewhat smaller in diameter and concave as a whole; that is to say, it diminishes instead of magnifies. Although Voigtlander, the first maker of this objective, constructed it with a smaller back than front—these being in the ratio of 2¼ inches to 1½ inches—yet did some other makers form both front and back of equal diameters. The first element of this back lens is formed of a bi-concave crown glass, the radii of the

surfaces being unequal; the second element is a flint glass meniscus, and this back lens both materially lengthens the focus of the front one and flattens the field, at the same time correcting the oblique pencils.

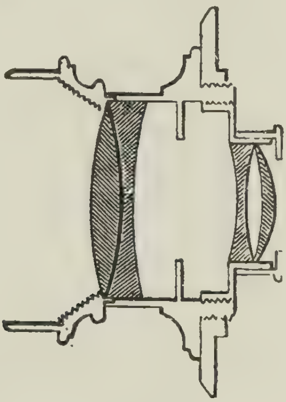

FIG. 25.

This it does in right of the fact that an oblique pencil falling upon a concave lens is powerfully affected by it, being considerably lengthened in focus. Indeed, with a combination of this nature, it is easy to have a back lens of such a kind so adjusted to the front as to cause the oblique pencils to be so much longer than the central ones, that the field shall be not merely flat but bellied in the opposite direction from that in which photographers are accustomed to see it.

Much was said concerning the equality of illumination possessed by the orthoscopic lens at the time it was introduced, and much was written, even by talented

opticians (*e.g.* Andrew Ross) to prove its superiority in this respect over the single achromatic landscape lens; but although the author possesses some of the best specimens of this kind of lens that have been made, he has quite failed to discover their superiority *in this respect* over ordinary lenses.

The Causes of Unequal Illumination.—These are, first, the fact that a pencil transmitted obliquely through a circular aperture (the diaphragm) is smaller than one transmitted directly or centrally through the same aperture; and, secondly, that the pencil thus transmitted obliquely is not merely smaller in diameter, but it has farther to travel and more work to accomplish. This is the case with every lens by which an oblique pencil is transmitted through a circular aperture.

Position of the Diaphragm in the Orthoscopic Lens.—The orthoscopic lens was somewhat extensively constructed by opticians after its introduction, and was sold under a variety of names. It is worthy of being noted that while Voigtlander placed the diaphragm behind the back lens, Ross inserted it between the front and back, while Goddard placed it outside of the front lens. It is difficult to surmise why he did so, unless on the supposition that realising the optical or focal centre was quite outside of the front lens, he sought to minimise distortion by having the stop as near to that centre as possible.

A Unique Property in the Orthoscopic Lens.—A special virtue possessed by the orthoscopic lens, and by no other, consists in the ability of obtaining with it larger sized

images in the negative with a given extension of camera than can be obtained by any other lens extant. The size of the image depends upon the focus of the lens by which it has been taken. The focus of a lens is measured from and determined by the position of its focal centre; and while this in a single landscape lens is rather nearer to the ground glass than the lens itself, it is in the orthoscopic combination, as just stated, outside of the lens entirely, so that, with a given length of camera, a much larger image of an object can be obtained by the orthoscopic lens than by any other. This is a property of great value.

Goddard's Double Periscopic.—The name of James T. Goddard occupies an honourable position among those opticians who have directed their efforts to the introduction of lenses different from those which previously existed, in order to eliminate with more or less success their inherent faults.

Among lenses introduced by Goddard was a rectilinear landscape objective which he designated his 'double periscopic' lens. This was in January, 1859. Externally this lens was of double convex form; but there was an air-space inside, and it was constructed as follows: The front surface was that of a biconvex crown, cemented to a biconcave flint, these two forming a meniscus combination without any positive or magnifying power. Cemented by its margin to this was a meniscus of crown glass, the residuum of the over-correction for colour of the front portion effecting the correction of this meniscus. Used with a diaphragm

in front, this objective was free from distortion. Its marginal definition, however, is inferior to another since constructed, on the same general principle, by T. R. Dallmeyer, and as an independent invention, he not then being aware of Goddard's lens. See pages 46 and 47.

Goddard's Triple Lens.—About the same time as the 'periscopic' was introduced, Goddard constructed a triple objective, the front of which was an ordinary shallow achromatic meniscus, the centre lens being a biconcave and the back a deep meniscus. The centre lens was smaller than the others, but neither it nor the back lens was achromatised. The front achromatic and the back meniscus were of similar foci, the power of the intermediate concave being such as to neutralise the magnifying power of either of them.

Goddard's Combination Landscape Lens.—This lens, introduced at the same period as the two preceding, has an achromatised front of meniscus form. The anterior of the back combination is a biconcave of crown glass, the posterior being a meniscus also of crown. The curvatures of these two are such as to prove that they possess no magnifying power. The distance apart of the front and back combinations is not an arbitrary one, but may be altered to suit the circumstances of each case. When separated somewhat, the marginal definition is much improved and the field flatter than when they are brought close

FIG. 26.

together. The focus of the combination is, therefore, that of the achromatic meniscus; and Goddard's idea was to supply a variety of these mounted in separate cells so that the photographer having a mount containing one correcting back lens—for he (Goddard) preferred giving the achromatic lens the anterior position in the mount—could make use of several achromatic lenses of any required focus.

The advantages claimed for the combination just described were freedom from distortion, flatness of field, and the ability for adapting a number of front lenses, each varying in focus from another, to the combination. On referring to some notes made when inspecting Goddard's work-book after his death, we find that he frequently departed from the form shown in the above diagram, occasionally, *inter alia*, adopting the plano-concave instead of the double-concave form for the crown, and sometimes separating the two crown glass lenses to a considerable extent.

Sutton's Symmetrical Triplet.—In 1860 Thomas Sutton introduced a lens under this name. It was composed of two achromatised plano-convex lenses of similar foci, mounted at either end of a tube, with a simple bi-concave lens in the middle. The power of this latter was such as to neutralise either of the outer two, but only few of them were made.

Dallmeyer's Triple Achromatic.—A special form of triple lens which secured a great degree of favour among photographers is shown in Fig. 27, which represents the triple achromatic combination of J. H.

Dallmeyer. The flatter surfaces of the front and back lenses are slightly concave, differing to this extent from a triple lens subsequently introduced by Thomas Ross,

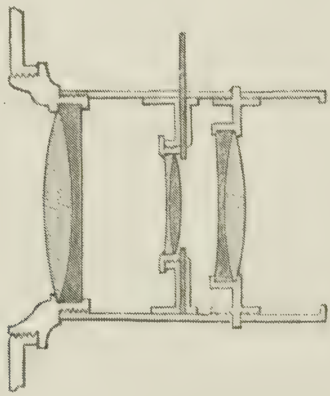

FIG. 27.

in which these surfaces were quite flat. The triple just shown, together with the others mentioned in this chapter, is quite free from distortion.

By increasing the diameter of the middle lens, Dallmeyer subsequently constructed a triple objective having an angular aperture sufficiently great to enable it to be employed for groups and portraiture.

CHAPTER XII.

WIDE-ANGLE NON-DISTORTING LENSES.

Defining the Term.—It is difficult to draw a sharp line of demarcation between narrow angle, medium angle, wide angle, and panorama, seeing that they imperceptibly merge into each other. We may, however, hazard the opinion that an included angle of subject up to 25° fittingly comes under the first of these terms; one up to 45° being medium; whilst a lens that includes more than a view of which the base equals the focus, may be relegated to those of wide angle. But many wide-angle lenses include an angle of 90° on the base line, and hence the application of the distinguishing terms can at best be only approximative.

Sutton's Panoramic Lens.—This lens, which is doubtless the widest angle objective yet introduced, must at present be spoken of in the past tense, none of them being now made. It was composed of two thick concentric shells of flint glass, all the surfaces being measured from a common centre. It was in effect a sphere of glass, the space in the middle being filled with water. It was achromatic, and the spherical

aberration was sufficiently corrected to admit of its taking pictorially sharp photographs. An ingenious 'butterfly' diaphragm was devised, by which the extreme side of the image was illuminated with the same intensity as the centre. But at the time when it was introduced, it was imperative that the image had to be received on a curved or cylindrical plate, the printing-frame and other fittings being also curved, and this led to its manufacture being discontinued.

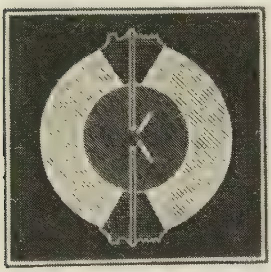

FIG. 28.

The objection formerly existing need not now prevail, for sensitive celluloid or other flexible plates can be placed in flexible or roller slides, and, by suitable curved guides at the back of the camera, can be temporarily bent in the cylindrical form and afterwards flattened out. The author has ascertained from actual experiment the practicability of the suggestion here made, having taken by one of these lenses and on a celluloid film a panoramic view embracing an angle of 125° in the fractional part of a second—an angle exceeding by 5° that which the lens was originally computed to cover.

The Globe Lens.—This is an American production, so named because its external surfaces, like those of Sutton's, formed portions of a sphere relative to each other. It is composed of a symmetrical pair of deep

meniscus lenses, achromatised by the union of a concavo-convex flint cemented to a meniscus crown, the latter being placed outside, as shown in the cut. The diaphragm is in the middle of the objective. Some of the Globe lenses gave a flare-spot or ghost in the centre of the picture, and it does not seem to have occurred to C. C. Harrison of New York, the maker, to have set aside the 'globe' idea in their construction, and mounted them a little closer together. This slight modification we found to exorcise the ghost entirely.

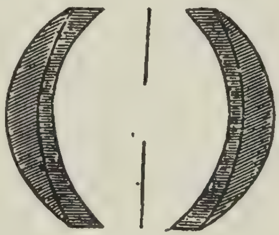

FIG. 29.

The 'Globe' was subjected to modifications by other makers of the period and country, but the same general feature pervaded them all.

Morrison's Wide-angle Lens.—Richard Morrison, on the death of Harrison, in whose employment he had long been, conceived an idea that some advantage, especially in construction, would accrue by slightly over-correcting one of the lenses of the 'globe,' and supplying the place of the other with a simple crown-glass meniscus. This idea was not quite original, for, so long ago at 1857, it was placed upon record that F. H. Wenham had had a lens (a narrow-angle one, however) constructed for him in which

FIG. 30.

the front was a plano-convex lens of crown glass, the back lens being an over-corrected achromatic, also of plano-convex form. We carefully examined a lens received direct from Mr. Morrison, and found that although the front lens was not really over-corrected for colour, yet that the addition of the crown-glass back did not appreciably affect its working to visual focus. Lenses of deep meniscus form possess a wonderful degree of elasticity as regards focus.

Steinheil's Periskop.— Professor Steinheil, about a quarter of a century ago, introduced a symmetrical doublet constructed expressly for including a wide angle. It was of simple form, being composed, as shown in the figure, of two simple or uncorrected lenses formed of crown glass. It embraced a very wide angle of view, but having an exceedingly small diaphragm it worked slowly in those days of wet collodion, and, besides, the visual and chemical foci were not coincident.

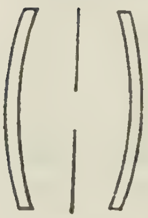

FIG. 31.

Zentmayer's Lens.—Josef Zentmayer, of Philadelphia, improved upon the Steinheil periskop by making it unsymmetrical, the back lens being of shorter focus than the front, and the diaphragm being placed nearer the back, in the ratio of the foci of each component.

The Doublets of Grubb and Ross.—We have to link these optical productions together, because both were introduced at the same period. It became more intimately associated with the name of Ross, as Thomas

Ross manufactured it in three different degrees of included angle, while the professional engagements of Thomas Grubb, as chief engineer to the Bank of Ireland, prevented him at that time from bestowing much attention upon it. A good idea of its nature will be ascertained from the figure, in which A is the front lens and B the back lens. By rendering the components of a more pronounced meniscus form and bringing them closer together, T. Ross made the objective include a still wider angle. Owing to the proximity of the diaphragm to the lenses, this combination is singularly free from flare.

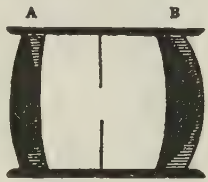

FIG. 32.

Genesis of the Doublet.—Before dismissing this lens, we present drawings of both the original and the last form assumed by it. Fig. 33 shows the objective made in 1841 for Henry Collen. In it both lenses were plano-convex; they were separated by a considerable space, had a rather small diaphragm in the centre, and gave a round field, so much so that when taking portraits by it (for it was constructed specially for portraiture) it was necessary to have the sensitive negative paper pressed in shape between two glasses bent in spherical form. The latest form of that doublet is shown in Fig. 34, which differs from that first shown by having its elements set closer together.

FIG. 33.

The doublet was in all cases made of flint and crown glass, and hence required a rather small diaphragm; but we have lately seen some lenses formed of two kinds of flint glass and figured like that shown on the previous page (see Fig. 32), which work with an aperture as great as that of our most modern lenses.

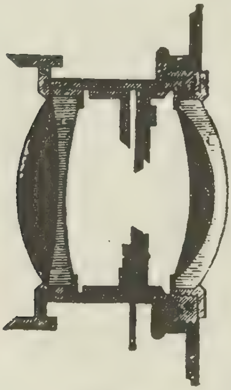

FIG. 34.

Davidson's Combination.—In 1841, Thomas Davidson, a well-known Edinburgh optician, constructed symmetrical lenses, concerning which it is worthy of notice that they were externally similar to the most approved rapid doublets of the present day. Each lens was formed of a plano-convex crown, cemented at its surface to a plano-concave flint. We had a lens of this flat class made by a son of Davidson more than a quarter of a century since, and so well did it work that it is doubtful if, with all our modern appliances, much better pictures can be taken now than were produced by this lens invented fifty years ago. Why, it may be inquired, was it allowed to fall into a state of desuetude? We reply: Davidson introduced it as a portrait lens, for which purpose it could not compete with the Petzval portrait combination introduced about the same time by Voigtlander. The processes practised in those days were slow, and the most rapid portrait lens was that which secured preference.

Dallmeyer's Wide-angle Rectilinear. — In this objective the lenses are both of the form in which the denser material of the achromatic lens is placed to the outside. Although Dallmeyer made them for the most part as shown in the figure, that is, with a front lens of larger diameter and longer focus than that of the back lens, yet are they also made symmetrical, especially those of short focus. They are formed of flint and crown glass.

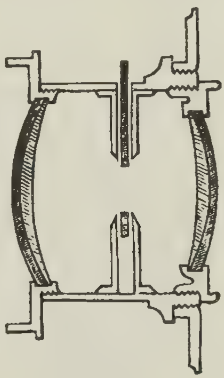

FIG. 35.

Steinheil's Wide-angle Aplanat. — Steinheil having recognised the advantages accruing from the exclusive employment of flint glass of different refractive and dispersive ratios, as employed in his *rapid* aplanat, afterwards constructed one on the same general system but of small diameter so as to be quite portable. The lenses were thicker than those usually made of similar diameter, and were set so closely together as in some instances to barely allow the diaphragm to be inserted between them. These lenses include a very wide angle, and are quite free from the flare-spot. They are manufactured by various makers, in many cases under the trade designation of

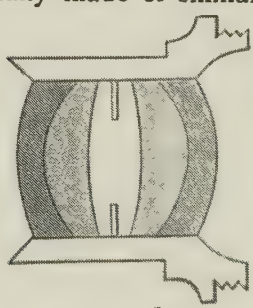

FIG. 36.

the Portable Symmetrical, which was first given them by Ross & Co., although other makers adopt different names. They work for the most part with an aperture equalling a sixteenth of their focus. A distinguishing characteristic of the Ross portable symmetrical is the identity of diameter of mounts and flanges of all the usual foci, and the great perfection of detail given by it over the large angle included.

Steinheil's Antiplanat.— This lens partakes of the nature of the orthoscopic objective to this extent, that the front lens is a positive and the back a negative combination, although the latter is so to only a very slight extent. It will be seen from the cut (Fig. 37) that the back lens possesses an unusual degree of thickness, this being necessary to correct the aberrations of the anterior combination. Steinheil makes the antiplanat in two forms, one having a larger angular aperture than the other. It is a triple combination. The other, which is intended for groups, is that which we have here figured.

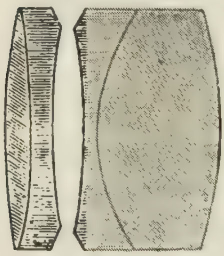

FIG. 37.

CHAPTER XIII.

PORTRAIT LENSES.

BY a portrait lens, or combination of lenses, is meant one having an aperture so large in comparison with its focus as to admit a volume of light of sufficient intensity as to enable portraits to be taken in the subdued light of a studio in the briefest possible period of time.

Being aplanatic, a portrait lens is capable of defining sharply without any diaphragm, although, as we shall eventually show, a diaphragm is indispensable for securing its full advantages. It may be urged that any lens by which a portrait is capable of being produced may be entitled to the designation of a 'portrait lens,' but in technical language the term is only applicable to those of a certain description, between which and the original landscape lens there are now so many grades as to render somewhat difficult the drawing of a hard and fast line.

History of the Portrait Lens.— The portrait combination is a triumph of optical skill, and in its original and general form is an emanation from the mathematician, Professor Petzval, of Vienna. The history of its inception may be told in a few words:— In

1840 Professor von Ettingshausen, having returned from a visit to Paris, where the daguerreotype process was engaging the attention of the scientific world, remarked to Petzval that Daguerre, with whom he had been in direct intercourse, made use of a lens having a small diaphragm, by which a great loss of light ensued, and inquired if he (Petzval) could not devise a better form of lens. Acting upon this hint Petzval instituted researches, and the year following (1841) gave to Voigtlander—at that time an optician enjoying a high reputation—the formulæ for two objectives, both of them working without a diaphragm. One had a large aperture and short focus, and gave great concentration of light over a large area; the other had a longer focus, and was capable of covering a large field. The former was the now well-known and universally-used portrait lens, the other being the orthoscopic, which was allowed to lie *perdu* for several years afterwards. A becoming distinction not having at that time been recognised between actinic and visual achromatism, the lenses of early times had what has been succinctly designated a 'chemical focus'—a fault which is now eliminated from the productions of every lens manufacturer of eminence. Thus much by way of remark on the early history of the portrait combination.

What is Angular Aperture?—The leading distinction between the portrait and other lenses is implied in the term 'angular aperture.' This it is which determines rapidity. Angular aperture has no relation to actual size or diameter of lens, except so far

as such relates to focal length ; hence a lens only one inch in diameter may be a much quicker-acting instrument than one of three inches, because of its aperture being larger in proportion to its focus. In making choice of a lens for rapidity of action care must, therefore, be taken to select one of short focus in proportion to its actual diameter. The acting angular aperture of a lens varies with every different stop that is used ; and it is frequently necessary to reduce this aperture considerably—not for the sake of weakening the light and thus protracting the exposure, but in order to confer a greater degree of penetrative power, for 'depth of focus' is in the inverse ratio of large angular aperture. When a comparison of lenses is made in order to determine which is the better, both should be as near as possible of similar diameter and focus; because two lenses may be of the same diameter—say three inches—but one of them having a focus of six inches and the other of twelve inches, the difference between the two as regards rapidity will be this—that the one of twelve inches will necessitate an exposure four times longer than that required by the other in order to obtain equally exposed negatives. Again: two lenses may have the same focus, one of them having a diameter of three inches, while that of the other is only one inch and a half. The former possesses four times the intensity of the latter, and will work in a fourth of its time. A just comparison cannot be made between two lenses of the same focus but dissimilar dimensions unless both are stopped to the same extent.

The portrait objective consists, as shown in the adjoining diagram (Fig. 38), of two achromatic lenses of dissimilar form mounted at some distance apart. The anterior lens is a plano-convex, or, more usually, a meniscus of such a slight external concave curvature as to seem to a cursory observer to be plane. Its component parts are a crown glass double-convex,

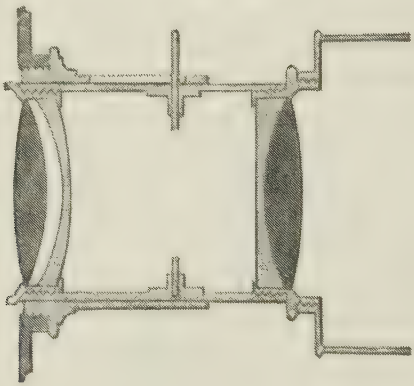

FIG. 38.

attached by transparent cement to a plano-convex flint lens. The posterior lens is a double-convex composed of a bi-convex crown and a concávo-convex of flint glass. The inner curves of these are not concentric, as in the anterior lens. They are usually mounted so as not to touch each other, and when tested as a whole will be found lacking in the power of bringing rays to a sharp, or even moderately sharp, focus.

Properties of Back Combination.—The back combination of a portrait lens fulfils a twofold function:

it shortens the focus, and thus aids in conferring intensity of illumination; it also distributes over a flat field the image formed by the anterior lens, which, without the correcting influence of the back lens, would be sharp only over a very limited area. This is the principal function of the back lens, and it performs it because of its excess of negative spherical aberration — a property that will be observed readily if the posterior combination be employed as a magnifier in the examination of any printed matter, when it will be found that the focus of the centre is shorter to a considerable extent than that of the margin. Seeing that this property of negative aberration is modified by the distance apart of the elementary components of the posterior lens, it is frequently possible to convert a bad lens into a good one by a slight adjustment of this portion of the objective. Many portrait combinations have the back lenses placed loosely in the cell, with a flat ring of brass between to keep them apart. An objective of this class, four and a half inches in diamcter, intended for 15 x 12 negatives, which performed very badly in consequence of its roundness of field, the centre of the picture only being sharp, had the separating ring of the back components entirely removed, and with marked advantage. This posterior combination was now found to have its negative aberration greatly increased, for the separating ring was half an inch in width. Now, as the anterior lens of the objective was of much shorter focus than the back one, it was considered necessary, in consequence of the

now increased negative aberration of the back, to bring the front and back lenses much closer together. Accordingly, after a few trials the tube was shortened to the extent of an inch and three-quarters, with the gratifying result of the objective working in an exceedingly satisfactory manner, and taking a sharp portrait on a 15 × 12 plate—the full size it was intended to cover. This incident is mentioned because a bad lens was converted into a good one without a necessity being experienced for regrinding any of the surfaces.

Dallmeyer's Back Lens.—A form of back lens, differing from that of Petzval, was introduced several years ago (1866) by J. H. Dallmeyer, in which both the forms and the relative positions of the components

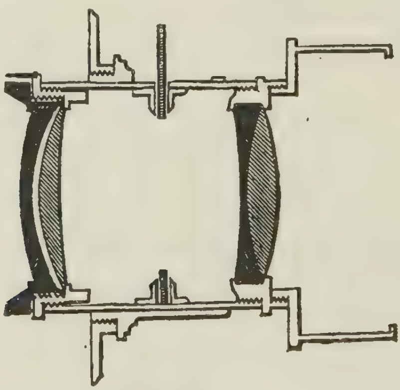

FIG. 39.

are reversed. Its nature will be ascertained from the diagram (Fig. 39), in which the back lens is seen to consist of a shallow meniscus formed of a con-

cavo-convex of flint (the convex side being nearest the ground glass) and a meniscus of crown. The two lens are so constructed that when placed as closely in contact as possible the objective will give sharp definition, but when separated in even a very slight degree spherical aberration is introduced to any desired extent, thus lowering the definition. This form of back combination is now adopted by some of the leading Continental opticians, who burnish the two lenses in one cell, thus discarding the advantage conferred by separation of the constituents.

Waterhouse Diaphragms.—All portrait objectives of any pretensions to the highest quality are now fitted with diaphragms. At first these were inserted in the hood of the lens, and kept in their place by a ring the width of the hood. It then occurred to Mr. Lake Price to slit the tube so as to drop in one of a series of loose diaphragms between the lenses; but the invention is now associated with the name of Dr. Waterhouse, who further simplified the system.

Discoloured Glass.—We have spoken of angular aperture as the great requisite towards rapidity; but there is another which, while less essential, is of great importance. We refer to quality of glass. Both crown and flint optical glass are sometimes apt to be a little 'off' the colour even when made, and it is a well-known fact that discoloration occurs in some lenses by merely exposing them to a strong light. This will be more specially alluded to in a subsequent chapter.

CHAPTER XIV.

RAPID LANDSCAPE, GROUP, AND COPYING LENSES.

Nature of a Rapid Lens.—What constitutes a rapid lens is not very easy to define. That a portrait combination, having a large angular aperture, is really the most rapid worker of all no one can for a moment entertain any doubt; and yet it is not 'rapid' in the sense in which we have now to speak of the instrument, but must be suffered to remain outstanding, and yield the phraseological distinction to others much slower.

The term, first introduced by Mr. Dallmeyer to distinguish one of his rectilinears, may be considered as now applying to combinations constructed for the purpose of including a wider angle than the portrait lens on the one hand, and a smaller angle, on the other, than can so easily be obtained by the wide-angle, non-distorting lenses which were described in the preceding chapter. Any combination which will include a moderate angle of view, such as two-thirds of its focus, with an aperture from *f*-6 to *f*-10, and be free from distortion, is entitled to be considered a 'rapid' or aplanatic lens.

The first of this class of which we possess any record

was issued in July, 1866, by the late Dr. Steinheil, at the suggestion of the late Dr. Monckhoven, who supplied the required data which should be kept in view in the construction of such a lens as was at that time considered a desideratum. The instrument which resulted from a conference between the two *savants* possessed an aperture equalling one-seventh of the focus. It was formed of two different kinds of flint glass. But in a patent obtained by Mr. J. H. Dallmeyer about the time of the issuing of the Steinheil aplanatic lens—as the new claimant for public favour was designated—the principle upon which this lens is constructed was embraced ; for in the specification of the patent which has primary reference to the wide-angle rectilinear described and figured in our last chapter, together with the back combination of his portrait objective, and which patent was obtained in the course of the year above mentioned, he says :—' A lens may be constructed according to my invention of flint glass only, necessarily of two different kinds as regards density for the production of achromaticity, instead of, as is usual, crown and flint glass.'

There is ample evidence that these two *workers* were employed in independent investigations, although in the matter of publication Steinheil had the priority.

Modifications. — Although the general principle of construction is similar in all of the 'rapid' type of lenses, with one exception, yet several modifications as regards curvature and densities of glass have been made by the respective manufacturers of this rapid

doublet. The accompanying diagram (Fig. 40) is sufficiently accurate to describe nearly all 'rapid' lenses (with the one exception alluded to) by whomsoever they are constructed. Each achromatic lens in the combination is a meniscus formed of dense glass, the denser element forming the side that is convex. The elements in each are a concavo-convex and a meniscus cemented together, and two of these form the objective, the apertures of which, according to the maker, may be considered as varying from f-4 to f-10. The former of these, however, implies that glass has been made use of having a degree of density scarcely safe to be employed for photographic lenses on account of its tendency to become discoloured.

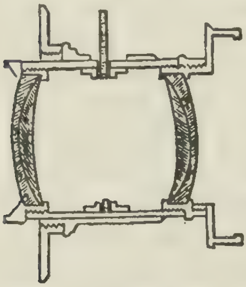

FIG. 40.

Advantage of Dense Glass.—Why, it may be asked, employ glass of such great density? Or what advantage does heavy, dense glass possess over the lighter sort known to be unalterable by either light or time? We reply: the denser the material of which a lens is constructed the greater is its refractive power, and, consequently, the flatter is the curvature required to produce a lens of any definite focus. We here repeat what we have already stated, that if three single lenses are required of similar short foci, all being the same diameter, and the first be composed of diamond (if that were practicable), the second of dense flint glass, and the third of light crown glass, then, while the first

would be comparatively flat, the last would be very thick, owing to its short radius of curvature, while the second would be between the two. Now, seeing that the radius of curvature of a dense glass is so much greater, for its diameter and focus, than one of light material, the spherical aberration is diminished in a corresponding degree. It is impossible to produce with ordinary flint and crown glass a combination of the form shown in the foregoing diagram which shall work with an aperture as great as those formed of dense glass. Hence the advantage of the latter kind of glass.

Symmetry.—Symmetry in a *rapid doublet* (by which name we shall designate this class of lens, by whomsoever manufactured) is not at all a requisite condition towards obtaining either a large angular aperture, covering power, or rectilinearity of projection. Some years ago a statement was made by the author to the effect that for all purposes, except that of copying an object the size of the original, the lenses of a rapid doublet, examined from the non-distorting point of view, should not be symmetrical. This drew forth, first, the strong animadversions of the deceased Thomas Sutton, whose mathematical ability no one doubts; and, secondly, an adverse private expression of opinion from the then mathematical adviser of a large optical firm who now in practice *ignore* strict symmetry. Such is the irony of fate! A vast number of the rapid doublets now being manufactured have their front lenses of longer focus than their backs. This dissimilarity is sometimes carried so far as to cause a sensible difference in focus

of the combination when the full aperture and a small stop are respectively employed. The reason underlying this dissimilarity of elements in an objective have relation to the law of conjugate foci. But photographic optics is so much a series of compromises that it is unwise to dogmatise upon what should be the way to carry into effect a certain idea, as it is impossible to indicate any one mode as being the best. The form of rapid doublet shown in Fig. 39 (*ante*) is that which is adopted by all European manufacturers, and it is a necessity of their construction that glass of greater than ordinary density be employed in their formation. It may be an abnormally dense crown glass united with flint glass of a corresponding ratio of density to secure the requisite actinic correction; or it may be a light flint glass combined with heavy flint, the result being the same.

Morrison's Rapid Doublet. — The rapid doublet of Richard Morrison, an American manufacturing photographic optician, formerly spoken of and lately deceased, appears to have been projected on lines totally different from those of European opticians; for, not only is it formed of the ordinary optical flint and crown, but the very principles involved in its manner of correction differ from them. In Fig. 41 we present a diagram of this American rapid doublet, the curves of which are none of them deep in any part, differing in this respect from the internal or contact surfaces of the European class, the radius of which is always very short. From what we have seen of this American objective when tried in comparison with those of the European form there

does not appear to be much difference between them. There are numerous particular instances in both classes in which one has proved much superior to the other;

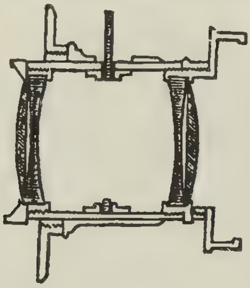

FIG. 41.

but in the best specimens of each the difference between the photographic results is not readily apparent. *A priori*, the European form should possess such an advantage over the American as is to be obtained from the reflecting surfaces being only half the number; for the interior surfaces of the Morrison lenses being dissimilar as regards curvature, it is, of course, impossible that they can be cemented. This in practice, however, is not a matter of the importance that might at first be imagined from the 'loss of light' point of view, because a very slightly increased diameter of lens will amply compensate this.

Where the real point of danger is apt to lie, if care be not taken in properly adjusting their various parts is in the increased number of images formed along the posterior axis by these various reflecting surfaces. The Morrison rapid doublet, if gifted with speech, might

hurl a *tu quoque* against its European rivals; for it is the case that by many of the rapid doublets a central flare spot will be produced if the conditions are such as to favour its production.

What we have said regarding this objective comparing favourable with the European rectilinears, must be held as applying to narrow angles of view only; for, as might be deduced from a perception of its shallow curves, the Morrison doublet cannot, from the very nature of its construction, transmit an oblique pencil in the perfection capable of being attained by the cemented combinations of European form just described; hence for including other than a narrow angle of view it must yield the palm to them.

CHAPTER XV.

UNIVERSAL LANDSCAPE LENSES.

What Constitutes a Universal Lens.—By 'universal,' in the above heading, is here meant adaptability or adjustability of focus. The photographer has his camera pitched at the one point from which alone the composition of the subject is perfect, but when focussed upon the ground glass it is found that either too much or too little of the scene has been got in. Then why not carry a battery of lenses, so that when one fails in delineating upon the ground glass just so much as is wanted and no more, it may be deposed in favour of another which will better fulfil the requirements of artistic composition? While such an expedient is to the individual possessing ample means the most satisfactory that could be adopted, it is open to the serious objection of great expense and much bulk—especially the former. Having one mount it is, of course, easy to adapt to it a variety of lenses set in cells, each lens either set far back or made to project in its cell according to its focus; for it is scarcely necessary to remark that the longer the focus of the lens the greater must be its distance, *cæteris paribus*, from the stop.

Convenience of the Universal System.—This system is much to be commended, as it enables the photographer

to reduce his *impedimenta* to a considerable extent without having to sacrifice efficiency or convenience in any degree. During a series of discussions on landscape lenses which took place at the Photographic Club, the author, speaking on this subject, showed a mount of convenient dimensions to which he had, by suitable adapters, fitted lenses by Grubb, Ross, Dallmeyer, Darlot, and others. These packed into a pocket-case by themselves; and by making a selection he could have every focus, either singly or in combination, for which his camera was adapted. These were not mere makeshifts, but each was adjusted according to strict rule. Many years since M. Darlot, a Continental manufacturer, devised and executed a cabinet of lenses for a similar purpose. Casket lenses are now being made by several manufacturers.

Universal Lens on New System.—Perhaps the most useful lens of all, should it ever reach the stage of being manufactured, will be that which was referred to by the author as having been devised by him, but as yet in a too unfinished state for detailed publication, namely, one in which, by the rotation of a collar or the movement of a button in a slot in the mount, the focus of the lens—complete in itself—is susceptible of being altered to a considerable extent. That such really can be done there is no room for doubt, as we have made use of such a combination, constructed somewhat roughly, but sufficiently well to show the action. The alteration of the focus is caused by the movement to and fro of certain lenses, more especially of a concave achromatic, so con-

structed as not to interfere with chromatic correction no matter how effected. A principle analogous to this has for some time been applied to a low-power microscopic objective by Carl Zeiss, Wray, and others.

A Focus Adjuster.—A convenient form of focus adjuster, which we devised and had constructed several years ago, consists in a sliding piece of brass, made

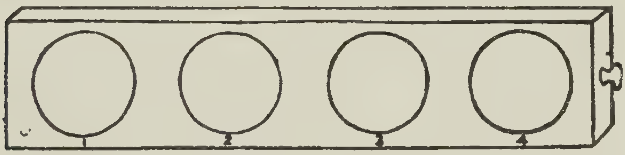

FIG. 42.

hollow in order to secure lightness, of the form shown in Fig. 42. It contains four apertures, into each of which is fitted a thin achromatised lens of a negative power. This piece slides through the lens mount, by means of an aperture, shown in Fig. 43. There are a series of notches on the slide so as to ensure the lens connected therewith being kept quite central. The combination to which this system is attached is a doublet composed of two slightly meniscus lenses which, when used alone, do not give a flat field. By inserting the slide the influence of either of the four

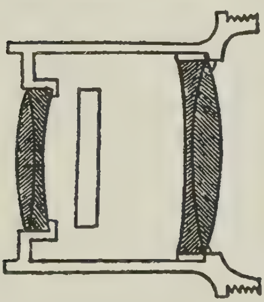

FIG. 43.

concave lenses contained in it is to flatten the field and

lengthen the focus—the marginal pencils being well corrected with a moderately large aperture. With No. 1 lens the equivalent focus is seven inches, the other concaves increasing the focus respectively in the following proportions:—

No. 1	7 inches.
„ 2	9 „
„ 3	12 „
„ 4	15 „

When not in use this slide packs away in a neat little pocket-case, six inches long by one and a half inches wide, and half an inch deep. This forms a compact and useful appendage to a lens. If one of the lenses of the combination be removed an entire change of focus is produced; but in this case it is lengthened so much as to be useless when employed with a small camera. A series of three auxiliary lenses mounted in similar fashion was prepared and long used by us in connexion with the Petzval orthoscopic system, the performance being so good as to have elicited from a clever manufacturing optician an expression of surprise at what he termed the great adaptability and elasticity of this system.

Every one knows that there is a horn or shell pocket magnifier which can be obtained for a few shillings, and which consists of three lenses of different powers set in horn and hinged on a common pivot, so as to rotate in or out as required. These lenses being of different foci form a tiny battery of seven degrees of magnifying

power, according as they are employed singly or in combination with one another; and something analogous in principle to this in photographic lenses is what we contend for as a tool that would prove highly useful to landscape photographers. There is much optical talent lying dormant among photographers. We trust that what has been here said will prove the means by which some of this inert power may be aroused.

The Elements of Combinations may be used as Single Landscape Lenses.—In connexion with this subject we may remind photographers who employ combinations of lenses, such as those of the rectilinear or symmetrical class, that each lens may be used singly as well as in combination. The focus will then be *about* twice that of the complete objective. But this is not always the case, as many lenses of this class are dissimilar, the front being of longer focus than the back. This is all the better as regards diversity, as it affords three changes. But when employing only one of the elements of this objective as a single landscape lens the best effect is not obtained if the lens be screwed into the tube in the usual way. It is then rather too close to the stop. But by having an adapting ring into which it can be screwed, so as to allow of a greater distance between it and the diaphragm, its full value will then be ascertained. The central definition will be good under all circumstances; but when the stop is close to the lens the marginal definition is bad, but will improve in proportion as the space between the stop and lens is increased, until it reaches its maximum extent of improvement. One such

adapting ring (which we have had made to adapt to the single lens of a combination) of one inch and five-eighths in diameter, possesses a width of three-quarters of an inch. When the objective employed in its completed state is a double combination everything is right; but when the front lens is removed then the stop is found to be three-quarters of an inch too near to the remaining lens to produce the flattest field when using it alone.

Incidentally and *apropos* of what has just been said in relation to increasing the flatness of field by placing the stop at the proper distance in front of the lens, we may here remark that sometimes, even when making use of a *single* achromatic lens, a flare spot is found on the centre of the plate. This has been denied by some; but the fact remains that, under certain circumstances, some single achromatic lenses do offend in the manner indicated. This subject is more fully treated in the chapter on flare and the flare spot, in which the remedy is described.

If the combination which is to be separated for the purpose of employing only one of the lenses be a wide-angle one, then the back lens may be removed and the front one left *in situ*, convex surface to the view. This is an entire reversal of the circumstances under which a landscape lens is usually employed; but in the case of the lens just indicated it will prove best, especially if the angle to be included is not great.

CHAPTER XVI.

FLARE AND THE FLARE SPOT.

FLARE may be described in general terms as an abnormal transmission of light through the lens whereby the brilliance of the image is impaired. It is sometimes caused by reflection from the mount of the lens, and more usually by reflections from the lens itself.

Flare from Imperfect Mounting.—In some objectives the lens is retained in its cell by a counter screw formed of a short piece of tube having a thread on its outside, its inside being blackened, occasionally by staining the metal, and not unfrequently by means of a coating of dead black varnish. The former of these is altogether bad. To realise this it merely suffices to point the camera towards a brightly lighted scene, and, having laid aside the ground glass and thrown a large focussing cloth over the head, direct the eyes towards the mount of the lens to observe what an amount of light is reflected from the various parts of the setting. Then let it be remembered that all such reflected light thus observed will fall upon the sensitive plate and degrade the brilliance of the image.

When the counter screws are finished with dead black varnish, there is but little light reflected at first; but after a while, when the surface of the lens has been frequently wiped with a soft cloth to free it from dust, the action of the cloth upon the black varnish of the cell ultimately converts the dead surface into a shining one which is a powerful reflector of light.

In some of the lowest priced objectives the lens is dropped into a recess at the end of the mount and is retained in its place by a ring screwed in. This is a more fertile source of flare resulting from mounting than any other. We have known an offensive flare produced in a landscape lens by a high-class maker by the hollowing of the cell around and outside of the lens, which after its dead black varnish got brightened by cleaning the convex surface of the glass with a wash-leather, reflected as would a parabolic reflector the light radiated from the surface of the sensitive plate.

The Remedy for Flare from Mounting.—By coating the brass work with dead black varnish, a receipt for which will be found in another chapter, flare of the nature described will be greatly diminished if not entirely cured. The edges of all lenses should also be blackened previous to their being set in their cells; this is done by applying the black varnish by means of a camel's hair pencil.

The Optical Flare Spot.—No lens, not even one of the simplest class, has ever been made that does not give two images of any luminous body in front. One of these is, of course, the primary image formed at the

principal focus ; but there is another which is to be found in the axis, and usually very close to the posterior surface of the lens.

Take any lens, a common reading-glass for instance, and interpose it between the flame of a lamp or gas. Now look at the lens with both eyes, and a small, bright, and inverted image of the flame will be seen at a distance of an inch, more or less, from the lens. It is very easy to locate its precise position and to receive the image upon a small bit of tissue paper or ground glass ; while, if desired, the primary image of the flame may be simultaneously received at the principal focus farther back. Now, an achromatic lens gives a small secondary image just the same as does the reading-glass, and arises from the same cause. What we wish the reader to bear in mind at present is the fact that the relation of the small image to the gas flame is that of conjugate foci, demonstrated by causing the lens to approach close to or recede from the flame, when the image changes its position accordingly.

Cause of the Secondary Image.—Most of the rays are transmitted through the lens to the principal focus, but a few are arrested by the back surface, and are reflected to the anterior surface only to be re-reflected back again and transmitted. The result of the refraction and reflections they undergo is to bring them to a focus quite close to the lens. Of those rays which do not undergo the reflection from the front surface, but which come to a focus on the opposite side, we shall presently speak.

The Flare Spot in Landscape Lenses.—When a diaphragm is placed before a lens, the aperture therein has the same relationship to it as had the gas flame in the former case ; that is to say, the small bright area of the stop will be reproduced as a circular spot of diminished brightness behind the lens. As this has a conjugate relation to the lens, it is possible by bringing the diaphragm moderately close to the objective to form an image of the aperture at the primary focus, or upon the sensitive plate. But as a very slight alteration in the position of the anterior conjugate (the diaphragm) makes a great difference in the posterior one, it merely suffices to make such slight alteration in order to effect a cure. In some cases such a trivial alteration as an eighth to a quarter of an inch suffices to convert a bad lens into a good one, as it may bring the ghostly image forward from the plate to a position near to the lens whence it is distributed over the the entire surface in a state so attenuated as to be harmless.

Flare in Compound Lenses.—In proportion to the number of reflecting surfaces in a combination so does the number of false images increase. Let a Petzval portrait combination be taken into a darkened room and directed to a lamp, and it will be found that along its axis no fewer than fourteen images of the flame will be seen, four of them erect, and ten inverted. Of all combinations this one seems the worst to work with a diaphragm and escape the presence of a more or less bright flare spot. To avoid this evil it is much the better way, when using it out of doors with a bright sky

in front, not to employ any stop at all, but to use it with full aperture.

Flare in Rapid Rectilinears.—In cemented doublets of the 'rapid' type,' now in such general use, it will be found, when directing it to a lamp or gas flame, as in the previous experiment, that the number of reflected images is reduced to five or occasionally to six. Of these, one depends to a greater extent than the others upon the degree of the separation of the front and back components, and there is a special distance at which they may be separated where the concave surface of the front lens will be seen to be one blaze of light. To show that this arises from reflections from the back lens, it is only necessary to increase or decrease the amount of separation ever so slightly to cause it to disappear. The flare spot in this class of lens is most pronounced when the distance at which the lenses are separated is such as to give this reflection, the relation between the diaphragm and the back lens also being such as to have the image of the former thrown on the sensitive plate.

To Ascertain whether a Lens gives Flare.—A good way by which to discover the presence of this flare propensity in any lens is to screw it into a camera and focus a view of an ordinary gas flame on the screen, the room being otherwise darkened. This image will be sharp, bright, and inverted. Now move the camera slightly so as to cause the inverted image to be a little to one side of the centre of the focussing-screen, and in nine cases out of ten there will be seen a ghostly image at the opposite side of the centre. This

secondary image is non-inverted, and upon rotating the camera it moves in the opposite direction to the primary image. The nature of this secondary image and the cause of its formation may be examined in the following way: move the camera so that the ghostly image shall be near the margin, and then, placing the eye in the line of that image and the lens, withdraw the ground glass, when the posterior surface of the lens will be found to be quite luminous.

That the false image is, in this case, caused by a reflection from the back surface of the anterior lens is demonstrable by unscrewing the cell containing it until it is almost ready to drop out of its tube, and then, keeping an eye upon both the primary and the secondary images on the ground glass, move or slightly wriggle the front cell, which, by its looseness in the mount may now be easily done, when it will be seen that, while the primary or legitimate image of the flame remains motionless, the flare image, caused by the reflection from the surface of the front lens, dances about all over the plate. But observe, further, that there is a certain distance between the front and back lenses at which this secondary image is sharp and bright; and in proportion as either the front or the back lens cell is screwed out or in, so does the image become more attenuated and expanded till at last it ceases to be seen altogether, while all this time the real image is not seen to suffer in any way.

The Cure.—This tendency of the ghostly image to pass out of focus with such extreme rapidity upon

separating the lenses by a few turns of the screw, or even by making them come nearer to each other, provides the means by which this annoying evil may be cured. A rapid doublet may be excellent for groups, copying, and every other purpose, and yet may break down when employed with a small stop in landscape work. This class of flare-spot is seldom, if ever, seen unless a small stop be used.

It does not follow, because there may sometimes be a mistiness or haze on the whole or a portion of a negative, that this indicates a defect in the lens. We have known it to be so attributed when in reality it was caused by the admission of light into the camera through a chink almost imperceptible to the eye. A tiny crack in the front of the camera, a pinhole in the bellows body, the absence or bad fitting of a screw in the flange—these and other causes may produce deleterious effects which may be wrongly attributed to the lens.

CHAPTER XVII.

THE EQUIVALENT FOCUS.

PREMISING that the solar focus of a lens is that point at which objects situated at a great distance are brought to a sharp focus, we now consider the nature of the 'equivalent' focus of a combination—a term which arises from a comparison with a single lens that would produce the same-sized image, one being equivalent to the other.

What is the Equivalent Focus?—The equivalent focus of a lens may be said to be the focus measured from the optical centre of the combination when such centre has been determined for a distant object. The term 'back focus,' in popular use, is altogether misleading, or, rather, it conveys no idea at all in cases in which accuracy is required. We give an instance, and in this case an extreme one: An objective may be formed having a back focus of only one inch, yet the real or equivalent focus of which shall be eight inches; in other words, the size of the image produced by the combination shall equal that produced by the use of a single lens of eight inches focus.

Out of several portrait combinations to be met with every day, and by makers of high reputation, a large

number may be selected almost identical as regards *back* focus, but not two alike as regards real or equivalent focus. We were present in the establishment of a dealer in lenses of home and foreign production when two portrait lenses were selected from a large stock and accurately paired, as was imagined, for the purpose of being employed in the taking of instantaneous stereoscopic views. Thorough care and honesty were bestowed upon the selection, the mounts were identical in every respect, and both were then brought under the influence of a single rack-and-pinion. So far all was right, and the images on the ground glass were sharp. Soon afterwards they were returned as not being a pair, in the sense of their producing images of different dimensions. This was an illustration of the misleading nature of back-focus measurement. It being of importance that the photographer should know the real focus of his lenses, we shall now give some methods by which this can be ascertained.

Rough Method of ascertaining the Equivalent Focus.—We commence by giving one which is, at frequent intervals, being discovered by some whose reading of photographic literature is limited, and paraded, especially in non-photographic serials, with all the trumpet-blowing of a great discovery. It is, unfortunately, not an accurate method, being so only in an approximate degree. For 'rough and ready' purposes, where exactness is not essential, it may prove useful. Focus upon any subject—such as a map or engraving—and let the arrangement be such that the image on the ground glass is precisely

of the same dimensions as the original. Now, measure the distance between the ground glass and the subject, and divide by four, which gives the figures required. But, as we have said, this method is not accurate in the case of a combination of lenses.

Grubb's Method.—Fortunately, there are several other methods by which the equivalent focus may be ascertained with unfailing accuracy, and in describing a few of them we commence with that which we almost invariably employ in preference to all others, being that in which the late Mr. Thomas Grubb has made the camera itself to do duty as a theodolite. In front of a window place a table covered with a sheet of smooth paper, which must be fastened to the table top. Now make a pencil mark at each side of the ground glass of the camera, a slight distance from the margin. This mark may consist of a line about an inch or more in length. Next direct the camera to any well-defined object at a distance—say, the top of a chimney, a flag-staff, the corner of a building, or any other suitable object—and rotate the camera so as to bring this object directly upon one of the pencilled lines on the focussing-screen. This having been done, with a pencil draw a line on the paper cover of the table, making use of the right-hand side base of the camera as a straight-edge for this purpose. Now, without disturbing the table, move the camera round until the object of which we have already spoken is brought directly upon the pencil mark at the opposite margin of the focussing-screen, and again draw a pencil line on the sheet of paper, using the right-hand side of

the camera for this purpose as before. (We may here state, *par parenthèse*, that the two lines thus drawn show the angle of view included within the space, hence this forms a simple method of determining the angular field given by any lens.) To resume: if necessary, extend the lines thus projected on the table and connect them by a line, as in the cross of the letter A, which is equal to the distance apart of the two pencil marks on the ground glass. The distance of the intersection of the first two lines and the third line is the equivalent focus of the lens.

A modification of the system described consists in determining the central point of the focussing-screen by drawing diagonals from the corners. Then select two distant objects, so arranged as that their images shall be equidistant from the central point. Measure with a pair of compasses the distance between the two objects on the ground glass, and, rotating the camera so that one of them shall 'cut' the centre mark, draw a line on the sheet of paper as before directed; then turn the camera until the second object shall in like manner correspond with the central mark, a second line being drawn on the table. Now connect these two angle lines by a third equal to the space between the compasses, and the distance between the junction point of the angle lines and the cross line is the focus.

The Pinhole Method.—Another method by which the equivalent focus of a combination may be ascertained is to observe very carefully the size of the image of any distant object given upon the ground glass, then remove

the lenses from the mount and insert—most conveniently in the cell for the stops—a thin plate of metal in which is a very small hole, such as a pinhole. Now move the lens mount in or out until the image thus obtained coincides in dimensions with that given by the lens; then measure the distance between the pinhole and the ground glass. This will be practically equal to the equivalent focus of the lens. Owing to diffraction, or the tendency of rays of light to bend when passing an opaque edge, it will be impossible to secure a very sharp image by this pinhole system. On this we may observe that although in geometric objects light is assumed to travel in straight lines in physical optics this is not the case, for on passing by the edge of an opaque body it is bent round the corner to some small extent.

Single Lens Method.—Instead of the pinhole system a better way is to obtain a cheap biconvex spectacle glass, which can be obtained in nearly any large town at a cost of one or two shillings per dozen. Select one that gives with a small stop an image the same size as the combination. Measure the distance between the centre of the glass and the ground glass, although, owing to the thinness of the lens, the measurement may practically be made from the outer surface. Greater accuracy is, of course, secured by adding to the measurement thus obtained the semi-thickness of the spectacle lens.

Rule-of-Three Method.—But it is not at all necessary that a large number of spectacle glasses be obtained for determining the equivalent focus of a combination, seeing that it may be effected by the use of one alone of any

known focus. Having taken the precise dimensions of any subject—and which we may designate the 'test object'—on the ground glass with the photographic combination whose focus is as yet unknown, do the same with the spectacle glass of known focus, and compare the two results. The relation of the sizes of the two images to each other is the same as that of the foci of the lenses by which they were produced. It is a simple rule-of-three problem.

Several other methods for ascertaining the equivalent or solar focus have been suggested, but those here given will serve every purpose, and may be practised very simply. Hence to avoid complications we confine ourselves to them.

CHAPTER XVIII.

CONJUGATE FOCI.

IF a lens which has been carefully focussed upon a distant object be then directed towards one comparatively near at hand, the nearer object will be found to be out of focus, necessitating the withdrawal of the ground glass from the lens before the image will assume its maximum sharpness. This establishes the fact that there exists a relation between the object that is focussed, as regards its distance from the camera, and the focus of the lens. This relation is termed '*conjugate foci.*' In what we have now to say we will speak of the distance between the lens and the object as the anterior or major conjugate, and that existing between the lens and the ground glass of the camera as the posterior or minor conjugate focus.

Conjugate Focus Illustrated.—Parallel rays *a a*—that is, rays from a great distance—falling upon a lens come to a focus at *f;* but those from *b*, which may serve to represent any object ten or twenty yards distant, have their focus at *c* (Fig. 44). Then *f* is the solar focus, *b* and *c* being the conjugate foci. The former of these is the anterior, and the latter the posterior conjugate. To

facilitate reference, the lines indicating the conjugate foci are solid, while those relating to the solar focus are

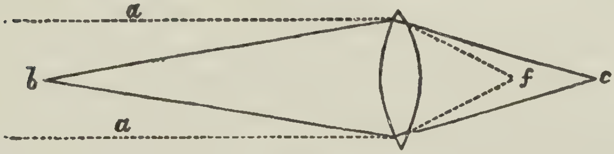

Fig. 44.

dotted. The points *b* and *c* are interchangeable; an object placed at either is sharp at the other.

Laws governing Conjugate Foci.—The laws which govern the conjugate foci are to be found—not, perhaps, so clearly expressed as the practical photographer would require—in several old optical treatises. The following, which amount to nearly the same thing, although expressed differently, will be quite sufficient for introduction in this chapter:—

Claudet's Rule for estimating Conjugate Foci.—If the principal or solar focus of a lens be regarded as the unit of measure, an object situated in front of the lens at a distance from a certain point, equivalent to a multiple of the said unit, will have its conjugate posterior focus at a distance from another certain point equal to a corresponding fraction of the same unit. This relation of the conjugates to each other, although probably first published in an old work (Dr. Smith's *Optics*), was first brought before the world in relation to photography by the late M. A. Claudet at the Aberdeen meeting of the

British Association (1859). The following popular illustration, which was given at the time of the first publication of the proposition in *The British Journal of Photography*, serves to make it more readily understood:—Suppose we have a lens of twelve inches solar focus—an object situated at a distance of *six feet* from a certain point in front of the lens, that is, at six times the unit of measure —the conjugate posterior focus will be at a distance of *one-sixth part* of the same unit; that is, at two inches distance from a corresponding point behind the lens.

The 'point' here spoken of before or behind the lens is the solar focus measured from the optical centre of the combination, or, as we described it in the previous chapter, the centre of conjugate foci.

Brewster's Rule.—Previous to the publication of this, one of the methods usually adopted to calculate the conjugate foci was that of Sir David Brewster, which, however, was of little or no use when applied to other than a simple lens:—Multiply twice the product of the radii of the two surfaces of the lens by the distance of the radiant point from the centre of the lens for a dividend. Multiply the sum of the two radii by the same distance, and from this product subtract twice the product of the radii for a divisor. Divide the above dividend by the divisor, and the quotient will be the focal distance required.

From what was said in the previous chapter, it will be understood that the range of posterior conjugate focus extends only from the solar focus, which is the nearest point to the lens at which a focus of any kind can be

obtained, and that focus which results from having the object so near to the lens as to give an image of the same dimensions as the object, and which, as we have shown, is twice the solar focus.

Grubb's Method and Table.—Soon after the publication of M. Claudet's method, as just described, the late Mr. Thomas Grubb directed his attention to the proposition with a view to its still further simplification and perfecting for photographers' use. We here present two tables in juxtaposition—No. 1 containing four ratios constructed in accordance with M. Claudet's method; No. 2 being based upon the shortcoming of the other, in which there is nothing to indicate any ratio required except that of 1 to 1, and in which (viz., in No. 2) Mr. Grubb adopts in preference the more simple and natural ratios of the actual distances from the lens.

No. 1.			No. 2.
1 f and 1 f	...	...	2 f and 2 f
2 f and $\frac{1}{2}$ f	...	...	3 f and $\frac{3}{2}$ f
3 f and $\frac{1}{3}$ f	...	...	4 f and $\frac{4}{3}$ f
4 f and $\frac{1}{4}$ f	...	...	5 f and $\frac{5}{4}$ f

In the above f denotes the principal focus of the lens, or feet when the focus is = one foot.

In table No. 2 the proportions required are at once apparent, while the numbers denote the actual distances required to be used for a focus of one foot, the ratio being still of so simple a progressive nature that a table of any required extent may be constructed almost as quickly as the figures can be written.

Having given Mr. Grubb's table (No. 2), we here present in a condensed form his argument based upon it, and the simple arithmetical rule deducible therefrom, by which to determine the conjugates :—

Let it be borne in mind, first, that f represents the focus of the lens, and that this focus is assumed to be $=$ 1 foot, or unity ; and, secondly, that we do not alter the *power* of a lens by using it, whether for bringing parallel rays to a focus or for forming conjugate foci. What we do in the latter case is simply to use a portion of its power on one side, leaving the balance of its power to be exerted on the other side—the simplest case of this being that where we use the lens for forming *equal* conjugate foci, and where, the lens being one foot in principal focus, a power equivalent to a focus of two feet is used at one side, leaving an equal power to be exerted at the other side. Now it requires very little mathematical knowledge to perceive that we can only perform the operation of adding and subtracting such powers by treating them as fractions—that is, by using their reciprocals ; and thus, as we express the adding of two halfpennies, namely,

$$\tfrac{1}{2} + \tfrac{1}{2} = 1 = 1 \text{ penny,}$$

we in like manner must, in adding the two before-mentioned of two feet each in focus, adapt the formula (p and p^1 being put for the respective powers) :—

$$\tfrac{1}{p} + \tfrac{1}{p1} = \tfrac{1}{f} \text{ (and } p \text{ and } p^1 \text{ being each} = 2 \text{ feet).}$$

$$\tfrac{1}{2} + \tfrac{1}{2} = \tfrac{1}{1} \text{ or focus} = 1.$$

From this simple equation (calling the whole power of the lens 1, or unity) we gather that the sum of the

reciprocals of the powers, which are at the same time the required distances from the lens, must equal unity; that is, any two fractions whose sum is unity will, in their reciprocals, give relative distances of the object and image for a lens whose principal focus is 1—foot, yard, &c.

The rule deducible from the foregoing for finding the required distance for any proportional size of object and image, and for any given focus of lens, is: Add the required proportions together for the denominator of two fractions whose numerators are the separate numbers. Invert these fractions, and multiply the focus of the lens by each of these for the respective distance.

CHAPTER XIX.

THE PRINCIPLE OF CONJUGATE FOCI APPLIED TO HAND CAMERAS AND FOR ENLARGEMENT.

Hand Cameras. — One practical application of the principle of conjugate focus which, we believe, will come more into use than has hitherto been the case is in the taking of landscapes, without specially focussing for each subject. Every photographer is now aware that, if he focus a distant object very sharply, and then make a mark on the adjusting portion of his camera, no re-focussing will ever afterwards be required when taking a distant object, all that is necessary being to slide out the camera until the previously made adjustment marks coincide. In like manner adjustment marks may be made for objects situated at a half, a quarter, an eighth, or a sixteenth of a mile as the anterior conjugate. The value of this will be specially appreciated under a twofold class of circumstances, namely, when by accident the focussing-glass gets broken; but more especially when the object to be photographed is in motion, precluding the possibility of

staying in order to have it focussed. To focus ships in motion, especially from the deck of another ship also in motion, is altogether out of the question when the whole powers of the photographer are taxed in observing the fitting moment at which to touch the exposing trigger. In such a case the proper procedure is to estimate as nearly as possible the distance at which the ship is from the lens (the acquisition of such guessing power being by no means difficult), and then adjust the sliding portion of the camera to the corresponding mark.

Enlarging and Reducing.—It is, however, in the production of enlargements and enlarging requirements, together with those employed in copying of every description, that the use of a knowledge of the laws of conjugate foci will be exceptionally useful. A photographer is supposed to be desirous of knowing what dimensions, as regards length, he should adopt in constructing a camera in which he will be able to copy a picture or object several times larger or smaller than the original, and to know how far from the lens must be the object on the one hand and the ground glass on the other. He is further supposed to have two or three lenses of different foci, but of the precise equivalent focus of each of which he has made himself well aware by one of the methods described in our last chapter.

Now let that focus, whatever it be—whether it be five, six, eight, or nine inches—be represented by *f*.

This is the only known element in the inquiry at the present stage. What is now required are the two positions in which to place the negative (represented by n) to be enlarged and the focussing-glass respectively, so that a sharp image shall be produced, no matter what may be the degree of enlarging. Expressing one focus of the lens by u and the other by v we have the following:—

$$(1)\ u = (n + 1) f, \text{ and}$$
$$(2)\ v = f + \frac{f}{n}$$

which, when converted into simple language, means—

(1) Add one to the times of enlargement (or reduction) desired, and multiply the sum by the equivalent focus of the lens. The product is the length sought for.

(2) To find the other conjugate focus: Divide the equivalent focal length of the lens by the times of enlargement (or reduction) required, and add it to the equivalent focal length. The sum is the length sought for.

The above embraces the whole subject of enlargement and reduction, even though the degree of enlarging be such as extends to the production of a life-size picture from a small miniature.

Table of View Angles.—The following useful table, calculated by Dr. C. E. Woodman, of New York, was published in the *Photographic Times* during its editorship by the author.

DIVIDE THE BASE OF THE PLATE BY THE EQUIVALENT FOCUS OF THE LENS.

If the quotient is	The angle is	If the quotient is	The angle is	If the quotient is	The angle is
	Degrees.		Degrees.		Degrees.
·282	16	·748	41	1·3	66
·3	17	·768	42	1·32	67
·317	18	·788	43	1·36	68
·335	19	·808	44	1·375	69
·353	20	·828	45	1·4	70
·37	21	·849	46	1·427	71
·389	22	·87	47	1·45	72
·407	23	·89	48	1·48	73
·425	24	·911	49	1·5	74
·443	25	·933	50	1·53	75
·462	26	·954	51	1·56	76
·48	27	·975	52	1·59	77
·5	28	1·	53	1·62	78
·517	29	1·02	54	1·649	79
·536	30	1·041	55	1·678	80
·555	31	1·063	56	1·7	81
·573	32	1·086	57	1·739	82
·592	33	1·108	58	1·769	83
·611	34	1·132	59	1·8	84
·631	35	1·155	60	1·833	85
·65	36	1·178	61	1·865	86
·67	37	1·2	62	1·898	87
·689	38	1·225	63	1·931	88
·708	39	1·25	64	1·965	89
·728	40	1·274	65	2·	90

Example.—Given a lens of 13 inches equivalent focus; required the angle included by it on plates respectively 3¼ × 4¼, 4¼ × 6½, 6½ × 8½, 8 × 10, 10 × 12, and 11 × 14.

(1) Dividing 4·25 by 13, we have as quotient ·327—midway between the decimals ·317 and ·335 of our table; therefore the required angle is 18° 30′. Similarly

						Degrees.
(2) 6·5	÷	13	=	·5;	corresponding to	28.
(3) 8·5	÷	13	=	·654;	,,	,, 36.
(4) 10	÷	13	=	·77;	,,	,, 42½.
(5) 12	÷	13	=	·923;	,,	,, 49½.
(6) 14	÷	13	=	1·08;	,,	,, 57.

CHAPTER XX.

A MECHANICAL MEANS OF ESTIMATING CONJUGATE FOCI.

In the previous chapter the means for ascertaining conjugate foci involve a certain amount of calculation, although not much.

Sir Howard Grubb's System.—But for the numerous class of photographers who dislike mathematical calculations, a method has been devised by Sir Howard Grubb, F.R.S., a method so simple and withal so accurate as to have elicited the highest encomiums from those competent to form an opinion. We give it in Sir Howard's own language.

Draw on a board, wall, or floor, a square A B C D, each side of which is equal to the focus of the lens; produce two adjacent sides of the square C B and C D. At A insert a pin or nail. Now place a rule or straight edge and rocking it on the pin or nail there inserted, observe where it cuts the prolonged sides of the square, as at M and N or M′ and N′.

No matter what position you place the rule in (always provided it rests against the pin at A and cuts the prolonged sides of square), the distances C M

and C N will represent a pair of conjugates for that *particular* lens. If it be required to enlarge or diminish by four, six, or any definite number of times, it is only necessary to rock the rule on the pin till one of the distances C M is four or six times more or less than the

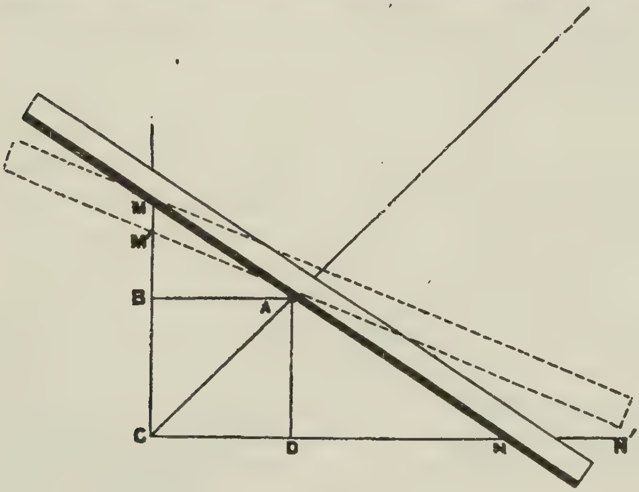

FIG. 45.

other C N. In other words, a lens of any focus equal to C B will form an image of an object placed at a distance of C N at the points C M, &c.

Similarly, if the focus of the lens be not known, but that the distance is known at which an image is formed behind lens of any object at a known distance in front of same, and that it is desired to know the focus of that lens: measure off the distance of the object from lens

on a horizontal line as at C N and the distance of image from lens on a vertical line as at C M, lay straight-edge across them and observe where this cuts the diagonal line as at A, then draw A B parallel to horizontal line, and C B or A B is the solar focus of lens.

The above, which may prove useful to those engaged in enlarging operations, depends upon the fact that in the figure given :—

$$\frac{1}{CM} + \frac{1}{CN} = \frac{1}{CB} \text{ or } CB = \frac{CM + CN}{CM + CN}$$

Now as this addition and subtraction of reciprocals enters very largely into many optical calculations, it will be seen that the above is only one of many cases in which this graphical method may be utilised.

Immediately after Sir Howard sent us the account of this system for publication we lost no time in having it constructed, which we did by fixing on a thin slab of wood two ordinary rules graduated to feet and inches, one placed vertically as at C M, the other horizontally as C N. The diagonal line C A was a slot in which travelled a pin or stud with a pinching screw behind, by which it was capable of being adjusted to suit the focus of any lens, the distance between the stud and vertical or horizontal rules equalling the focus of the lens.

A piece of apparatus of this kind, which every one can make for himself at a very trifling expenditure of money or labour, is a thing which we can strongly recommend to all who have to do copying or enlarging, as the major and minor conjugates of the lens—the positions respectively of the negative and the sensitive

surface—can be ascertained at a moment for any given degree of enlargement or reduction.

The Camera Club Focimeter.—When devising a focimeter for the use of the Camera Club, Mr. Lyonel Clark, C.E., selected as a basis that of Sir Howard Grubb, just described, to which he made some additions, so as to render it applicable for any establishment where enlarging on a large and varied scale is carried on. For the following drawing and description we are indebted to Mr. Clark.

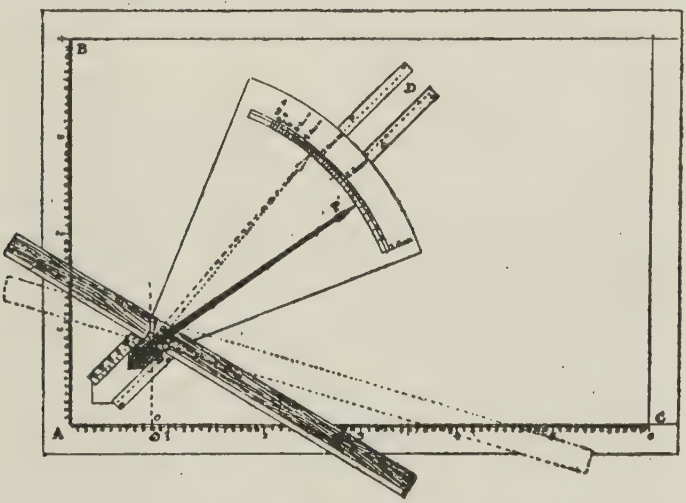

FIG. 46.

This apparatus is constructed for lenses of any focal length, but for amateurs who only use a lens of one focal length it can be made in a more simple form.

To construct the simpler form of apparatus you lay off a right angle, B A C, and divide its two sides, A B, A C, into feet and inches; the length of A B, which represents the major conjugate, is of course determined by the extension of the enlarging camera or easel. Not to have too bulky an apparatus, the sides will best be divided to some scale, say one-quarter or one-eighth.

You next divide the right angle into two equal parts by the diagonal A D; to obtain the correct position of the pin P, on which the straight-edge rocks, you have to erect a perpendicular on either side at the division on the scale corresponding to the focal length of the lens to be used.

In the cut the slide is set for a 10″ lens, and therefore the perpendicular, O P, is erected at the 10″ mark on A C, and the spot, P, where O P cuts the diagonal, A D, is where the pin has to be placed. Against this pin any ordinary straight-edge is rocked. It is, of course, best to let a small piece of brass into the straight-edge, through which the pin is inserted; this prevents shifting. The straight-edge is furnished with an index, or pointer, P P′. This is best placed, for the sake of symmetry, not at right angles to the scale, but 22½° less.

For a large establishment, where lenses of different foci are used, the straight-edge, with its pivot, pointer, and quadrant, are carried on a moving piece and can slide up and down the diagonal A D, which is now divided off in a continuous scale of foci. These, of course, are obtained in the same manner as the single focus was obtained.

The manner of graduation is done by calculating out a series of diameters of enlargements for one known lens. We need only deal with one conjugate, preferably the major, A C. The equation for this length is $(n+1)f$, where $n =$ number of times of enlargement, and f the focal length of the lens. Now we can take the focal length of our lens as anything, we will make it unity in inches, and the equation becomes $n+1$; that is, the length of the major conjugate is the number of diameters of enlargement *plus* one (expressed in inches). To enlarge one diameter—that is, to obtain an image of equal size—it is $1+1$, that is, 2; for 2 diam. 3; for 3 diam. 4; and so on. As one inch is so small a thing to deal with, it is best to take 10″ as the focus of the lens. This only alters the decimal point; 2 diam. is still 30 inches, and has the advantage that each added inch represents a tenth of a diameter. So practically, setting our index (the *fleur de lys*) at 10″, we swing the straight-edge until it cuts the 20″ mark on A C, and there mark the spot at which the pointer, P P′, stands as 1 diam.; moving the straight-edge to 21″ we mark off from the pointer 1·1 diam., at 22″ = 1·2 diam., at 23″ = 1·3 diam., and so on for each succeeding inch.

The scale of diameters of enlargement thus laid out is true for whatever lens we like to adjust our slide to. Whatever focus we are using, if we set the *fleur de lys* to it, and then swing our pointer, P P′, to the number of diameters we wish to enlarge, we shall read off where the straight-edge cuts, A B and A C, the length of the two conjugates.

In the cut the *fleur de lys* is set for a 10″ lens, and the pointer indicates 1·65 diameters. We read off on the major conjugate, A B—that is, the distance from the lens centre to the enlargement—2′·2½″, and on the minor, that is, the distance from the lens to the negative, 1′·4⅛″.

Let us check this by calculation.

$$\text{The major conjugate} = (n+1)\,f$$
$$= (1\cdot65 + 1)\ 10''$$
$$= 26''\cdot5$$
$$= 2'\cdot2\tfrac{1}{2}''$$
$$\text{minor conjugate} = \frac{\text{major conjugate}}{n}$$
$$= \frac{26\cdot5}{1\cdot65}\text{ in inches.}$$
$$= 16''\cdot1$$
$$= 1'\cdot4''\tfrac{1}{8}.$$

The accuracy of result must, of course, depend on the care in the manufacture of the instrument.

It is, perhaps, hardly necessary to point out that in the case of reduction the figures remain the same, but the major axis is now the distance of the negative from the lens, and the minor axis the distance of the lens from the reduction.

CHAPTER XXI.

DEPTH OF FOCUS.

A Paradox.—In discussing this subject, we begin somewhat paradoxically by stating that there is no such thing as depth of focus. Optically speaking, the focus of a lens is a point; and in cases where, from aberrations, the rays from any object do not converge to a point, of such a lens it may then be said that it possesses no true focus at all.

But, it may be asked, How does it happen that if an object at a reasonable distance—say, a quarter of a mile—be sharply focussed, all objects beyond that will also be sharp? To meet this we say that if a lens of long focus capable of yielding a sharp image be employed, this will not be found to be the case. If the focus of an object at the distance of a mile be carefully found in a telescope of, say, eight inches aperture and proportionate focus, another object situated a quarter of a mile away from the former will be quite out of focus.

Brewster, in his *Treatise on New Philosophical Instruments*, shows that he was quite aware of this property in lenses, for he gives instructions how, by means of a graduated eye-tube, a telescope may be

constructed which shall, within certain limits, show the distance at which any object is from the observer. Were there such a property as depth of focus, it is evident that such a telescope could not be constructed.

The Nature of the Definition required in Photography.—But the image produced by means of a photographic lens is of a different quality so far as concerns sharpness from that formed by either a telescopic or microscopic object-glass, for the conditions required to be fulfilled by the former differ from the others. The sharpest possible definition of objects situated in various planes of distance—this definition not being confined to a limited spot in the axis of the object-glass as in the telescope, but spread over a field of considerable width—is required in the photographic lens.

A lens fulfilling the requirements of the photographer should not have a mathematical focus or a definite focal point, but should possess such a degree of aberration as to yield, with a moderate aperture, good pictorial sharpness of objects in various planes. We possess a whole-plate portrait lens, four inches in diameter, in which there was so little depth of definition that in taking a portrait when the tip of the nose was sharp, the eyes and mouth were quite out of focus. Of course we could, by the insertion of a small diaphragm, bring both into equal apparent sharpness, but this entailed a prolonged exposure. But by destroying the optical perfection of focus which characterised this lens, we have now obtained such a balance of advantages, that with a wide aperture we have still pictorially good definition of the various

planes of the face and body, and a more photographically useful, although, optically, a less perfect instrument, is the result of the alteration.

Depth of focus, or, more correctly, of definition, is increased by the employment of a smaller aperture. By one of the diagrams in the second chapter we have shown the effect of a stop in producing sharpness by shutting out rays which would confuse. In the following figure we show the influence of the stop in extending the range of focus. With full aperture as indicated by

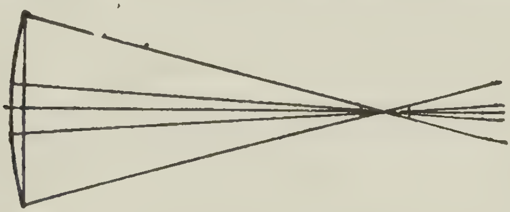

FIG. 47.

the two outside converging lines, the focus is at a definite point, the slightest removal of the sensitive plate from which would impair the definition. But suppose a diaphragm is inserted which admits only the acute angle of rays at the centre, then will it be seen to what extent the focal plane may be varied from the true focal point, without very seriously impairing the definition.

Objects served by Contracting the Aperture.—In a landscape lens, or, for that matter, in many other lenses, the contraction of the aperture by a stop serves the threefold purpose of enhancing definition by diminution of spherical aberration; depth of focus by causing the

converging pencil of rays to fall on the plate at a more acute angle; and flatness of field by extending the oblique pencils. When a stop is employed with a landscape lens, the focus received on the plate is not a mathematical intersection of lines forming a point, but is composed, so to speak, of a cylinder which can be cut at varying distances from the lens, within certain limits, without greatly impairing the definition.

Fixed Focus Lenses for Landscape Work.—Previous to the advent of the detective or hand camera, since which this has been better understood, the question has been frequently raised as to the expediency of having a rigid camera with a fixed lens for landscape work. The principle of depth of focus, or penetration, enables this to be successfully accomplished, for when the lens is focussed on distant objects, it is found that everything desired to be included in a view will be well defined. The shorter the focus of the lens, the greater is the depth of definition, so that in the case of two lenses—one long and the other short in focus—which are focussed on distant objects, the latter will include a greater range of sharply-defined objects in the foreground than the former. We have seen it laid down as an approximative rule by some writer on optics (Thomas Sutton, if we remember aright), that if the diameter of the stop be a fortieth part of the focus of the lens, the depth of focus will range between infinity and a distance equal to four times as many feet as there are inches in the focus of the lens. Assuming this to be correct, let us suppose that an operator in the field has two cameras, one with

a lens of four and the other of fifteen inches focus; in taking views with these from the same spot, the nearest objects which in the case of the larger instrument can be introduced will be at a distance of sixty feet, while with the smaller camera objects situated sixteen feet distant will be included with equal sharpness.

A few years ago a Committee of the Society of New York Amateurs was appointed to compile a table showing the range of focus for detective camera lenses. The following is the result. It shows the number of feet beyond which everything is in focus when the equivalent focus indicated is used. The disc of confusion is less than one hundredth of an inch.

Equivalent focus lengths.	Stop. $\frac{f}{5}$	Stop. $\frac{f}{10}$	$\frac{f}{15}$	$\frac{f}{20}$	$\frac{f}{25}$	$\frac{f}{30}$	$\frac{f}{40}$	$\frac{f}{50}$	$\frac{f}{60}$
2 inches	7	3½	2⅓	2	1½	1¼	1	⅞	¾
2½ ,, ...	10½	5¼	3½	3	2⅛	2	1½	1¼	1
3 ,, ...	15	8	5	4	3⅜	3	2	1¾	1½
4 ,, ...	27	14	9	7	5⅜	5	3⅜	3	2½
5 ,, ...	46	21	14	11	9	7½	6	4¾	4
6 ,, ...	60	30	20	15½	12½	10½	8	6½	5½
7 ,, ...	82	42	27	21	17	14	10¾	9	7½
8 ,, ...	107	54	36	27	22	19	14	11	10
9 ,, ...	137	68	45	34	28	23	18	14	12
10 ,, ...	167	84	56	42	34	30	21	18	15
11 ,, ...	202	101	67	51	41	37	26	21	18
12 ,, ...	241	121	80	61	49	41	31	25	21
13 ,, ...	283	142	94	71	57	48	37	30	25
14 ,, ...	328	164	109	83	66	56	42	34	29
15 ,, ...	376	189	125	95	76	64	48	39	33

CHAPTER XXII.

DIFFUSION OF FOCUS.

Meaning of 'Diffusion.'—The term 'diffusion of focus' is another name for spherical aberration. Some imagine that portrait lenses possessing this property have an advantage, not shared by others, of equalising the definition of varying planes; this, however, is an error, for there is no equalising of such different planes. But there is this advantage: that, whereas with a spherically corrected lens, when employed with a large aperture, one plane of the face—the eye, for example—is rendered microscopically sharp, the other planes—such as the ears and nose—are indistinctly delineated from being out of focus, in a 'diffusion' lens these various planes *appear* to possess a greater equality of definition, owing to the destruction of that excessive sharpness of one plane by which the others, by comparison, were degraded.

Advantage of Diffusion.—We are not now speaking of that depth of focus (which, we have shown, cannot exist from the strictly optical point of view), or depth of definition which arises from reducing the working aperture of a lens, but of that quality of non-optical definition arising from spherical aberration in the objective. Now,

while we like a lens that shall 'cut sharp as a razor,' we also like the power, when occasion demands, of making a picture that shall not be quite so sharp.

This is a very natural want felt by every photographer who does not consider the acme of perfection to lie in definition. Mr. Fox Talbot found the need of such a power even when using paper negatives, and recommended the separation of the negative from the sensitive paper by the interposition of a sheet of thin paper or gelatine as a means of obtaining this requirement. Others have suggested putting the sensitive plate a little out of focus; but an objection to this is found in the fact that if the face of the sitter be out of focus some other portion will be sharp, and Charybdis is no better than Scylla. If a lens have a moderately large aperture, and is not only properly achromatised but aplanatic, it is impossible to escape this extra-sharp definition of one plane. Every possessor of a large telescope is well aware that if it be focussed sharply upon an object situated at a distance of a mile an object only half a mile away is altogether out of focus; and so it is with photographic lenses within a more limited range. In order to remove this property some means must be utilised by which the lens can be rendered non-aplanatic.

The term 'aplanatic,' we here pause to say, was first employed by a Scotch *savant*, Dr. Blair, who in 1791 made use of it to signify certain points of superiority in lenses which he had constructed. Its application since that time has been narrowed down to signify freedom from spherical, in contradistinction to chromatic, aberration

The first Diffusion of Focus Lens.—The first account upon record of any lens in which the aplanatism could be modified at will, so as to secure either sharpness or 'diffusion,' was given in April, 1864, in the course of a paper read before the Photographic Society of Scotland by the author. When exhibiting a lens which he, as an amateur, had constructed for his own use, he directed special attention to the fact that by a slight re-arrangement of the lenses, operated by a projecting button working in a slot in the mount, the fine, crisp definition given by the lens in its original state was eliminated, and that in the altered condition it gave a picture *generally* sharp all over the plate, but particularly sharp nowhere. 'The lens,' he said, 'suddenly becomes possessed of a new property, which is the much-disputed one of depth of focus, or, more strictly, depth of definition, covering a large flat field without any stop whatever.' This, it is believed, is the first exhibition of any lens for which such a property was claimed, and special attention was at the time directed to the advisability of securing a lowered degree of sharpness in this mode rather than by the common method of putting the subject a little out of focus. It is fortunate that lenses both by home and foreign makers are now easily procurable in which by a separation of the back lenses the focus may be blunted in any desired degree.

Dallmeyer's Diffusion of Focus Objective.—We have already, when describing portrait lenses of large angular aperture, referred (at page 78) to the back lens introduced by J. H. Dallmeyer, with the special object

of introducing any desired amount of spherical aberration by the separation of its components. The posterior of these is set in the main cell in such a manner as to be separated from its fellow by turning a graduated ring.

Optical Perfection not necessarily Desirable.—When, at a series of discussions on lenses, at the London Photographic Club, the author took occasion to attribute a certain degree of blame to the manufacturers of lenses—especially those of the 'rapid' and 'portable' class of compounds—for curtailing their usefulness by limiting the aperture in the fixed stop to that point at which optical crispness terminated, the representative of a large manufacturing firm who was present good-humouredly hurled a jocular anathema at the individual in question, whose first act, he said, upon obtaining one of their lenses was invariably to put it in the turning lathe and open out the fixed stop to the diameter of the lenses. This is precisely the course we are now about briefly to advocate, and its reasonableness will stand or fall by the soundness of the reasons adduced.

Advantage of Opening the fixed Diaphragm.—When a lens of the description specified gives, with its fixed diaphragm, *black* definition — by which we mean the rendering of a piece of printed matter in an unmistakably sharp, black manner without greyness or fuzziness—it may be considered as being optically perfect; but as every lens will do this when it is stopped down to a sufficient degree, the question for consideration is—What price do we pay for this, or what do we suffer in the way of cutting off the illumination? The larger the

aperture of the lens that does this the better is such lens; and in making a selection of a 'rapid' objective this is one of the points to which we always pay special attention, for some will not define 'black' unless the fixed stop be very small. Let us suppose that we have got an objective the diameter of the lenses of which is two inches, the fixed stop between the two being one and a quarter inch. If with such a working aperture it gave black definition, we would, without hesitation, have this fixed stop opened up to such an extent as upon trial would merge the black definition of the lines into grey, occasioned by the overlapping rays caused by the introduction of spherical aberration. It might be necessary, in order to have this accomplished, that the fixed aperture be increased to such an extent as almost to show light round the margin of the movable diaphragms, and two such lenses in our possession have been opened out to that extent. The advantages secured are—first, the ability to take a photograph with a far briefer exposure than was previously possible; and, secondly, the ability to take a portrait in which, while the sharpness is still of excellent degree, it is chastened or softened by the modicum of aberration so introduced.

Now the gain thus secured has been obtained without any loss whatever; for, if the razor-edge definition of the objective in its original state be required at any time, it can be immediately secured by the insertion of a diaphragm, by which, so far as light and crispness of definition are concerned, the lens is returned to its first state. We are informed that opticians would with plea-

sure send out their lenses with the fixed stop enlarged in the way and to the extent here suggested were it not there are many inexperienced photographers who could not use aright such a power were it conferred upon them, and who, misunderstanding the reason for the increased aperture, would be apt to decry the lens as being deficient in definition. While we sympathise with the opticians in the force of this objection, we recommend the propriety of the course suggested to those who, being already in possession of objectives of the class to which we now refer, are at liberty to alter them in their brass work as they see proper. To tamper with the glasses themselves would be highly irrational, the ability to do so being assumed.

Mechanical means for producing Fuzzy Pictures.—Some of the mechanical means employed in the production of portraits in which extreme sharpness has no place are rather amusing. Among these we may refer to a system not long ago patented by one of the most eminent photographers of New York City, which consists in placing between the camera and the sitter a gridiron arrangement containing several gas jets, by which ascending currents of air of varying densities from the flames disturb the sharpness of the definition and produce an alleged greater harmony. The pictorial results are designated 'vibrotypes.' A similar effect is obtained by having a trembling camera-stand, or by attaching a string from the camera to the floor and causing it to vibrate during exposure.

Claudet's System.—The method employed by M.

Claudet was much more philosophical. It consisted in moving the lens in and out of the camera, within certain limits, during the *séance*, so that whereas at the commencement of the exposure the nose may have been sharply in focus and the eyes or ears out of focus, or *vice versa*, at the conclusion these conditions were changed, the nose being then out and the ears in focus. The focus was thus distributed over the entire plane of the face. M. Claudet made a specialty of very large portraits, which necessitated the employment of portrait lenses of large dimensions; and there is no doubt that by the means just indicated he secured equalised definition over various planes.

Into the art aspect of diffusion of focus we have avoided entering, our attention having been confined to considering the question from the optical point of view.

Diffusion by Single Achromatic Lenses.—The value of a single achromatic lens of plano-convex or meniscus form in producing 'diffused' portraits is well known. It must be worked with a stop much larger than would be employed in landscape work. Portraits of large dimensions and great technical excellence have often been obtained by such agency.

CHAPTER XXIII.

TESTING LENSES.

Preparation of Camera.—In testing a lens it is important that the ground glass of the camera be so smooth or of such a fine grain as to permit of the use of a magnifying glass without the image suffering from granularity. The mere masking of this granularity by waxing or oiling the surface of the focussing-screen will not suffice; the grain must be fine in itself.

It is equally important that the surface of the ground glass be at precisely the same distance from the lens as that of the sensitive plate. This cannot be ascertained with the requisite accuracy by the usual method of pushing a foot-rule through the aperture in the front of the camera, observing how far it goes, and then trying in the same way a plate in the dark slide. A more accurate method consists in laying a straight rule across the focussing-glass frame, and inserting between the edge of the rule and the surface of the glass a slip of card cut in the form of a wedge, and observing the distance it can be inserted, making a pencil mark at the place where it touches the rule. Next insert a plain glass in the camera dark slide, and do likewise.

If the point of contact of the wedge be the same in both cases then both planes are coincident.

In this way a difference of a hundredth part of an inch between the plane of the ground glass and of the sensitive plate may readily be detected. If the wooden adapters in the dark slide be thin and the spring in the back be strong, there is a danger of the sensitive plate being forced nearer to the lens than it ought to be, and the focussing thus disturbed. More than one optician of eminence has had lenses of large aperture and unmistakable excellence returned for alteration owing to an imaginary fault caused by the strength of the spring.

The Points to be Tested.—These are various and will be treated individually. They comprise—covering power or area of illumination; achromatism, actinism, or coincidence of visual and chemical focus; astigmatism; flatness of field; surface finish; striæ and air bubbles; purity of glass; definition; flare; focus; rectilinearity; aplanatism; and spherical aberration.

Although these topics are treated in the other chapters, yet it may be well here to devote a few words to each.

Covering Power or Area of Illumination.—The area of illumination is circular, and its diameter determines the size of plate that can be got out of such a circle. We are not at present referring to the quality of the image that may be produced from centre to margin of such area, which may be good or bad, but to the mere illumination to the corners. The diameter of this circle

equals the diagonal of any plate (that is, measured from corner to corner), which will be lighted to the corners. Take the case of a whole-plate, *i.e.*, one of 8½ by 6½ inches, the diagonal of this is 10¾ inches, and no lens giving a less area of illumination than this latter figure will cover the plate. But if a panorama were wanted, then by employing a plate of only 3½ inches in height and 9½ in length could a greater angle be included. Let the possessor of any lens ascertain the diameter of its area of illumination and draw this on a sheet of paper, he can then by placing any plate upon this circle see at a glance whether or not the lens will cover it.

Achromatism or Actinism.—The focussing screen having been adjusted accurately, it is next desirable to ascertain if the lens has a chemical focus, or, in other words, whether the actinic and visual foci be so carefully adjusted that both shall fall on the same plane. Place seven or eight printed cards in a row on edge on a slab of wood, the distance between each being six inches. In addition to the printed matter, each card should be boldly inscribed with a figure in black ink. Having placed the slab on a table at a distance of ten feet, arrange so that the cards shall be all focussed as near the centre of the ground glass as possible, all of them being shown. By the aid of a magnifier focus sharply, without using a stop, the centre figure of the row, which, if seven cards are employed, will be marked '4.' Now insert a sensitive plate and take a picture; and, if on the subsequent negative the fourth card be sharper than the others, it proves the coincidence of the

two foci. Should, however, a card further away than that focussed upon be found to be the sharpest in the negative, it indicates that the lens is over-corrected for colour, or, as expressed by some, it has a back focus.

Visual Test for Over or Under Correction.—At this juncture it may be desirable that we give an easy method for ascertaining whether a lens has its blue and yellow rays brought to the same focus, or is 'under-corrected' for colour, which is the necessary condition in a photographic objective. Bring the lens to be examined into a slightly darkened room in which there is a gas-light burning, and, retreating several feet from it, hold up the lens so as to form an image of this light in the eye of the observer. The image must, however, be examined through an eyepiece of any good construction; we prefer the 'Ramsden' for this purpose. At the point where the image is sharpest there is but little colour; but, by bringing the portrait lens a little nearer, the flame, if the lens be properly corrected, is seen to be surrounded with a claret fringe, while on removing it to a greater distance than distinct definition, the light is fringed with green, proving that the blue and yellow rays are combined, and, as a consequence, that the chemical and visual foci coincide.

When a lens is not properly corrected for colour, over-correction is the direction in which the error usually lies, especially in foreign Petzval portrait combinations, and in almost every instance which has been brought under our observation, the front lens has been the defaulter.

Astigmatism.—Astigmatism is a serious fault for a lens to possess in any marked degree. It is closely allied with flatness of field—that is to say, it is usually produced in the endeavour to make a lens which will cover a flat field with a large aperture. A lens of this class will work quite sharply in the centre, but in proportion as an object (such as the head of a sitter) is made to occupy a position tolerably far from the centre of the plate so does the sharpness diminish, and no amount of racking the lens in or out will give definition equal to that in the centre. To test a lens for astigmatism, erect a black cross against a white background. What we find most convenient for the purpose are the astragals of an ordinary window. At any rate there must be a vertical line crossed by a horizontal one. Now focus these sharply on the centre of the ground glass, and it will be found that both lines, the vertical and horizontal, are well delineated and equally distinct. Next rotate the camera slightly so as to bring the crossed lines to either the side or the top or bottom of the focussing-screen, and again examine the image very carefully, when the want of sharpness will be most apparent. Rack the lens in and out, and a point will be found at which the horizontal bars will be sharp, while the vertical ones are so far out of focus as to be almost invisible, or, at any rate, to have their sharpness greatly impaired. Now manipulate the rack once more, and the vertical lines will become sharp, leaving, this time, the horizontal ones as a confused mass of indistinctness.

In a similar manner, provide a sheet of brown paper with a round hole in it, and fix it on the window. Direct the camera to it as before, and observe that when the image is thrown on the focussing-screen it is quite round, no matter whether the lens be racked within or without the point of true focus. Now rotate the camera so as to bring the image to the margin, as in the previous experiment, and, behold ! it is no longer round as before; for, when the lens is racked in or out, it becomes alternately elongated vertically or horizontally, according as the lens is nearer to or further from the ground glass than the best mean focus. When the lens is made to approach the focussing-screen, the luminous spot is elongated vertically; but when, on the contrary, the focus is lengthened, the spot expands horizontally.

It is only in lenses corrected for great flatness of field that astigmatism is usually to be found in a strongly marked degree, although it is present to a slight extent in almost every lens. A portrait lens, however, having a round field, is more likely to possess freedom from it than any other. The skilful optician constructs his objectives so as to have as little astigmatism with as much flatness of field as possible.

Flatness of Field.—The best lens is that one which, giving brilliant definition at the centre with a large aperture, shall with the same aperture maintain that brilliance and definition farthest away from the centre of the plate. Place the camera opposite any row of well-marked objects not within several yards—a row of

brick houses will answer—and focus with the greatest care on the centre of the ground glass. Note the extent of crisp definition, and how near it approaches the side of the picture. It will also do to focus on one well-marked object in the centre of the field and rotate the camera, observing how much it falls away when brought to the edge of the ground glass, and how much racking in is required to make it sharp there.

Surface Finish.—The quality of this property is ascertained by holding the lens against the light, gas being preferred to daylight, and examining its surfaces with a watchmaker's eyeglass or similar powerful glass. In this way lenses which have been imperfectly polished, or not properly smoothed at the stage prior to receiving the final polish, will be discovered to have a slightly granular surface. We have known lenses of this sort perform well, but it is none the less a defect which ought not to exist.

Striæ and Air Bubbles.—Striæ in the glass is discoverable by taking the lens into a room from which daylight is excluded, and, turning the gas rather low, examining the image by the gas. Step a few feet back from the light, and holding up the lens so that the whole surface appears one mass of light, move it slightly from side to side, and turn it partially around. In this way a very slight inequality in the density of the glass, or a want of homogeneity in its composition will be discovered, if such be present. Air bubbles, if only of small size, are not of the same consequence as striæ, for they do not affect the definition. As no light is radiated from them,

they act only as would so many specs of opaque matter of the same dimensions. The testing of glass previous to being ground into a lens is spoken of in another chapter.

Purity of the Glass.—The quickest acting lenses, *cæteris paribus*, are those the glasses of which are colourless. In some of the oldest combinations the crown glass element was of a pronounced green colour, which interfered much with their rapidity. To ascertain the purity of the glass, as regards colour, place the lens upon a sheet of white paper and note the degradation of colour, if any, that takes place when looking down upon it. If the discoloration be of a brown character, the lens will prove slower in action than if it be quite colourless. Some who have much work in copying paintings or coloured prints assert that they get a truer rendering of the value of colours when using a lens of dingy colour than with one formed of purer glass. In such a case the lens itself enacts the part of the colour-screen of pale yellow glass often employed to attain a similar end.

Definition.—One of the best test objects for definition in a lens is an enamelled watch dial with the seconds circle. Let this be placed at a distance of a few yards and well lighted, either by lamp or daylight. On focussing sharply, ascertain that the division between the black strokes forming chapters two, three, four, and twelve, and also the seconds, are all well made out.

Flare Spot.—Unlike the other tests, this one should be applied after a diaphragm has been inserted in the

lens. Let the camera be directed against a rather dark object, such as a tree in foliage, with a bright sky overhead; an ordinary window will answer, provided the lower portion be obscured by a sheet of dark paper. If there be a flare spot, it will be seen in the centre of the ground glass. This spot, as we have explained in a former chapter, is an image of the diaphragm, and single lenses as well as combinations are liable to it. Fortunately it is easily remedied. This test can also be made in a room lighted by gas or lamp.

Focus.—The various methods by which the focus of a lens is known are so fully described in Chapter VI. that we refer the reader to it, especially as some of the systems may from facility of application or otherwise be preferred by some rather than others, and to cite them here would be but unnecessary repetition.

Rectilinearity.—Place the camera quite level, and direct it towards any perfectly straight object, such as the wall of a house, the side of a straight window, or, in short, to anything that is quite straight, and, having focussed it in the centre of the screen, rotate the camera until the image is brought close to the margin. Note whether the image is now curved or if it preserves its straightness. In the latter case the lens is quite rectilinear.

How to Cure Over-Correction.—There are three methods by which the evils arising from over-correction may be cured. The first is that which will prove the most effectual and give the least trouble in future. It consists in removing the lens from its cell, separating its

components by immersion in water sufficiently warm to soften the Canada balsam by which the lens is cemented, and then regrinding the contact surfaces in tools of greater radius of curvature. Only few photographers are able to execute work of this sort for themselves; for, although many are quite facile in effecting any manipulation or original investigation in chemistry, others being equally expert in mechanical and artistic departments, the number of those who have entered the field of optics by way of experiment or amusement is very limited. A 'jobbing' optician will be more likely to undertake the regrinding of a lens than the manufacturing optician, who could scarcely be expected to go out of his way to execute a trivial order of this nature.

A method which was much employed when over-corrected lenses were more commonly to be met with than is now the case consisted in having a graduated scale engraved on the sliding tube, so that when a visual image was focussed sharply on the ground glass, the lens had then to be racked out a certain number of degrees in order to ensure the image being sharp in the negative. This distance is a constant one only for an object situated a definite space from the camera or in the major conjugate focus of the lens, and varies with every distance of such object. Were this not the case it would be easy to sink the ground glass deeper in its frame, by which the same end would be achieved. If a lens of this class must be employed—and it is a well-recognised fact that some will produce photographs

as sharp and fine in every respect as those in which the actinic and visual foci coincide—the best way by far to utilise them with a minimum of trouble and with freedom from all uncertainty is to adopt the system described in Chapter VI., which consists in inserting, in the manner of a Waterhouse diaphragm, a very weak lens, the power of which shall be such as, when inserted in its place, to lengthen the focus of the objective to an extent equalling the difference between the visual and chemical foci. If, then, the object be focussed when this auxiliary lens is inserted, and the lens be then withdrawn when the exposure is about to be made, the image will be quite sharp. It may, perhaps, be scarcely necessary to observe that in all cases when purchasing a lens we recommend that one having a 'chemical focus' should be avoided.

Aplanatism and Spherical Aberration.—To test a portrait combination for spherical aberration, the Shadbolt method is as good as, and more convenient than, any other. Cut a disc of thick brown paper of the same diameter as the front lens of the combination, and from the centre of this cut out a smaller disc seven-tenths of the entire diameter. There is thus a disc and a ring, the areas of which differ only a trifle from one another. Now, first insert the ring of brown paper, which will act as a diaphragm; and, having carefully focussed on a printed bill, take an impression, which should be clear and sharp. Next remove the ring of paper, and with a little gum or paste attach the paper disc to the centre of the lens, and without altering the focus take another

picture of the bill. If the spherical aberration be at all well corrected, the second picture should be nearly as sharp as the first; but if the correction be insufficient the latter picture will be more or less indistinct.

Again, focus some well-marked test object—the small bare branches of a tree against the sky will answer—without any stop, using an eyeglass to ensure accuracy, and mark the position on the camera. Next insert a rather small diaphragm, and rack the camera in and out till the greatest point of sharpness is ascertained. Mark the camera again, and then ascertain if the two marks quite coincide. If they do, then is the combination aplanatic or spherically corrected.

CHAPTER XXIV.

THE SHAPE OF THE APERTURE IN THE DIAPHRAGM.

Fallacies respecting Shapes of Apertures.—A popular fallacy existed at one time in a greater degree of strength than at present to the effect that the shape of the aperture in the diaphragm should bear a certain relation to the general form of the principal subject in the photograph. For example: a vertical slit instead of a round hole was believed to be the correct form when the subject was tall, such as a church spire or other similar vertically elongated subject.

In the case of portraiture an aperture somewhat like a keyhole has been proposed as that best adapted for this class of subject, while for landscapes some virtue is still by some imagined to be imparted to the illumination of the image if the aperture be wide at the base and tapered off to a fine point at the top, the imagined advantage consisting in a greater volume of light being permitted to reach the foreground than that by which the sky is produced.

Circular Apertures Best.—The best shape of aperture is circular, and the next best such a degree of departure from the circular form as shall most nearly confine the

transmitted rays to a condensed bundle. This embraces a circle (the iris diaphragm) formed of several blades, by the motion of which, regulated by a volute, the aperture may be expanded or contracted to a large extent, while a sufficient approximation to the circular form is still maintained. Next to this comes a square, which by the motion of two plates in opposite directions—as first described by the late M. Noton—is also applicable to an easy formation of an expanding and contracting aperture. The worst forms of all are those whimsical ones shaped sometimes like a bottle, sometimes like a pyramid erected on a circle, and, worse than all, like a slot.

It is not difficult to give a reason for such condemnation. Take the case of a sky and foreground as an example. For such a subject an aperture of an exceedingly tall pyramidal shape has been recommended as possessing advantages over others. This recommendation has been made by individuals who are not considered mere 'nobodies' in photography, otherwise it might be allowed to pass without reference; but it is worthy of notice that the recommendation has not been backed up by a single argument of a scientific nature. They imagine it *ought* to be so, and think that it really *is* so; and there the demonstration ends. Let us see in what manner this wedge-shape slot or aperture affects the foreground as contrasted with the sky of the landscape.

In a previous chapter it has been shown that, in a landscape lens, the margin of the picture must be formed

by the margin of the lens, the same conditions prevailing with the centre of the photograph. Any departure from this is attended by disadvantages, such as spherical aberration. In order that any photographer may satisfy himself that the shape of the diaphragm goes for nought in reducing the intensity of light upon the sky, it merely suffices that after placing the camera in position in front of a landscape he then removes the ground glass. Now, having placed his eye where the sky on the ground glass was, let him direct his vision towards the stop. This will demonstrate to the observer that he can see the whole of the aperture in the diaphragm. Let, now, the same thing be done from the position occupied by the sky, and precisely the same amount of aperture in the diaphragm is seen, showing that whimsicality in shape goes for nothing in regard to illuminating one portion of the picture more than another.

This applies also to the use of either a vertical or horizontal slit instead of a circular hole. If a set of parallel oblique rays fall upon the lens they do not all proceed in the same direction after transmission; but, according to the principles of spherical aberration, the focus of a pencil transmitted by that side of the lens farthest removed from the object whence the rays emanate will be much longer than those transmitted by the nearer margin of the lens. Hence a *slit* aperture will give confusion; but if a round aperture be substituted, all such confusion will cease to exist.

CHAPTER XXV.

EQUALISING THE ILLUMINATION OF SUBJECTS—SKIES AND FOREGROUNDS.

How to Obviate the Excessive Light from the Sky.—It is not only possible but quite easy to arrange a stop so that it will admit a much larger volume of light to the foreground of a landscape image than to the sky. Not only so, but if one side of a subject were in deep shadow or of a dark colour—such as a dense mass of trees on one side placed in contrast with a sunny, well-lighted object on the other—it is comparatively easy so to arrange matters as that one side will receive a more intense pencil of light than the other.

Much ingenuity has of late been displayed in the construction of shutters which, in falling, will permit of a longer exposure being given to the foreground than to the sky. But this can be obtained equally well by means of a shutter of the ordinary class, or by a prolonged exposure, provided the diaphragm be placed oblique to the axis of the lens.

The Oblique Diaphragm.—In demonstration of the foregoing we refer to Fig. 48, in which *a* represents a lens of any form; *d* is a diaphragm placed at a slope

instead of the right angle at which it is usually fixed. In this position it is directed downwards towards the foreground or less-lighted portion of the subject, the consequence of this being that the large volume of light bounded by the lines *r*, *r′*, and which comes from the

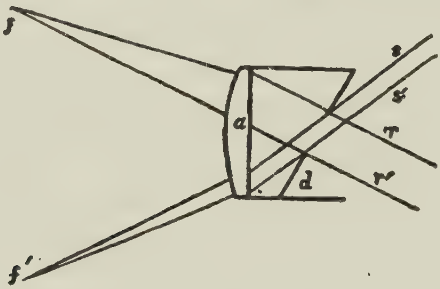

FIG. 48.

foreground, exceeds by many degrees that coming from the sky shown at *s*, *s′*; and these arrive at their respective foci *f*, *f′*, the one in a state of great attenuation in comparison with the other.

The principle of the oblique stop is the same whether it be applied to a single landscape lens, as in the figure, or to a combination. But we have found opticians very reluctant to adapt this oblique system to any lens. The usual working appliances, we were told, did not embrace the easy or effective cutting of a slot obliquely in the mount. To describe the several mechanical expedients we found it advantageous to adopt in having stops so arranged as to be capable of standing at any desired angle would be rather out of place in this chapter, espe-

cially as the mere indication of the remedy for under-exposed foregrounds is all that is here required.

Equalising by an Opaque Stop.—A system which we adopted a few years ago, with exceedingly satisfactory results, consists in placing at a little distance in front of the diaphragm a small piece of blackened brass of a V shape, base upwards. One or two trials will suffice to determine its best position. This fulfils the following conditions:—It gives a proportionately greater illumination to the foreground than to the sky, and, while it diminishes to any required extent the intensity of the light which falls upon the centre of the plate, it gives a great increase to that by which the sides are illuminated. Added to these, it costs nothing, and can be applied by any photographer to his lens without any disfigurement of, or tampering with, the brass work; for the whole appliance can easily be made and fixed in a couple of minutes by means of a pair of scissors, a bit of stiff black paper, and a little mucilage. When making our original experiments with this device we actually succeeded in turning the tables so that the foreground was far better illuminated than the sky, and the margins much more so than the centre, a wide angle of subject being included.

The unequal illumination of a negative, especially one of wide angle, is due to two causes. The centre receives a more intense impact of light than the sides on account of the pencil of light transmitted to it being both larger and having a shorter distance to travel from the lens to the sensitive surface. Not so with the

margins; for the stop with its circular aperture being placed obliquely as regards the margin the aperture is not then circular, but oval—a matter easily verified by looking through a stop, first directly, and then when turned in an oblique direction. This renders the oblique light less to begin with; but this attenuated light has also got much farther to travel than the stronger central bundle, and hence the marginal weakness.

The Butterfly Stop.—In the case of ordinary angles of view this difference is so little as not to merit much attention; but this is not so in the case of highly oblique incidences. To equalise the light by means of the stop in his panoramic camera the late Thomas Sutton devised a little adjunct of great ingenuity. It was a stop which, no matter whether held at right angles and looked at directly or at a very oblique angle, always presented a perfectly circular aperture. This was effected by two thin little wings of brass screwed upon the stop in such a manner as to effect the equalisation required (see Figure 28, page 66).

Bow's Method of Equalising.—We close this chapter by alluding to one other method suggested (by Robert H. Bow, C.E.) for causing the lens itself to be the equalising medium. It consists in having the crown or plate glass element of the lens of a delicate green colour, by which the thick centre will stop more actinic rays than the thin margin, the other portions of the lens acting in an intermediate degree.

CHAPTER XXVI.

ADJUSTING DISSIMILAR LENSES.

Matching Stereoscopic Lenses.—In matching a pair of lenses for stereoscopic purposes, serious difficulties have not unfrequently to be encountered. This difficulty scarcely, if ever, prevails when the lenses are of the single landscape class, but is most apparent in the case of combinations. Indeed, the difficulty of finding two portrait objectives so identical in focus as to produce pictures which, as respects dimensions, will be facsimiles is well recognised. Even when a number of lenses are made out of the same pot of glass, and ground to the same curves, marked differences will often exist in their foci.

Such being the case with lenses of a similar kind coming from one optician, the difficulty of obtaining two lenses alike, which have been made by different mechanics and of different degrees of curvature, is very greatly increased. It is, however, not only possible to bring two dissimilar lenses to absolutely the same focus without having to resort to regrinding and polishing their surfaces, but it is a matter which is not attended with so much difficulty as to be insurmountable by any reader of intelligence who possesses a moderate amount of me-

chanical skill. Let it, however, be understood that the two lenses must be of a focus not greatly apart from each other, although too much so to warrant their being used for binocular purposes.

Size of Image the Criterion by which Focus is judged.— The optical tyro must bear in mind the fact that the back focus, so called, of a combination, affords no clue whatever to the real focus of the lens. In comparing two lenses, the size of the image formed by each is the real criterion by which they are to be judged. There may be two lenses in which the back elements of each are precisely the same distance from the ground glass when both are sharply focussed, and yet the size of the respective images on the ground glass be widely different. The reason is obvious: the *equivalent* focus is that by which the size of the image is determined, and in a portrait lens the point from which the equivalent focus is measured—or the focal centre—has a very wide range of position, being in some combinations near the front lens, and in others near the back.

In combining two plano-convex lenses of similar foci —say of twelve inches each—these, if placed with their flat sides in contact, will have a focus practically of six inches, and it is not possible to make of these two any shorter focus than this. But by the mere expedient of separating the lenses, the equivalent focus may be lengthened to the extent of several inches; for the greater the distance between them—or, in other words, the longer the tube in which they are mounted—the longer will be the equivalent focus.

Bearing this in mind it becomes a very easy matter to adjust a pair of compound lenses of dissimilar foci, so that both shall produce images absolutely alike in respect of size; for if one give a smaller image than the other, and as by separating the lenses the equivalent focus is lengthened, a point will be found at which the images given by both lenses will be similar. It may here be noted that in proportion as the real focus is lengthened so is the back focus shortened.

In some instances the difference between the size of the images is so little that both lenses may be brought into coincidence by unscrewing the cell of the back lens a few turns. But if this proves insufficient, then should there be a short supplemental piece of tube screwed into the principal tube, and into which in turn is screwed the cell containing the back lens.

What has been here said of portrait lenses applies equally to every kind of combination, *e.g.*, rapid wide-angle rectilinears and symmetricals; and it will be obvious that the foci may be assimilated by shortening the tube of one lens as well as by increasing the length of the other.

Effect of Altering Lenses on Quality of Image.—There are lenses, especially those of wide angular aperture, so delicately adjusted as regards the separation of their elementary constituents as would entail a degradation of the definitions at the margin of the picture by altering them in the way suggested; but for the purpose here suggested it would be so slight as to be scarcely appreciable, while it *might* turn out, as it did in one

case under our observation, that the performance of the lens was greatly improved in every respect; and, at any rate the original mount is all the time unaffected.

Rule for Ascertaining the Focus resulting from Combining any two Lenses.—It may be well here to give the rule by which the focus resulting from the combination of any two lenses of known focus may be ascertained. Multiply the focus of one lens by the other, and divide this product by the focus of both added together, less the distance of separation. The quotient is the focus sought for. Thus—to take an extreme case as an example—if the two twelve-inch lenses previously spoken of, and which when in contact gave a focus of six inches, were mounted in a tube so as to be ten inches apart, the focus, instead of being six inches as formerly, would now be ten inches and (nearly) a quarter. Again, having two lenses respectively of twenty and twelve inches focus, and mounted two inches apart, what is the equivalent focus? The answer may be thus expressed—

$$20 \times 12 = \frac{240}{32 - 2} = 8 \text{ inches.}$$

The foci when added together give, minus two (the separation), 30, the divisor for 240 (the product of the multiplication of the foci) giving eight inches as the equivalent focus.

CHAPTER XXVII.

THE DETERIORATION OF LENSES BY LIGHT.

THE subject of the deterioration of lenses through time or carelessness on the part of assistants is one fraught with much interest to the photographer, who frequently has a large amount of money invested in them. Complaints as to lenses which were at one time rapid but have become much slower in action have been frequent. In some cases it is possible that imagination has to do with such deterioration; but, for all that, it is not less the case that the falling-off in the effective performance of a lens is a physical fact which admits of no gainsaying.

Colourless Glass a Factor in Rapidity.—The clearer and more colourless is a lens the better and more rapidly does it act. This may be accepted as an axiom in photography, although in astronomical instruments and microscopic objectives it is not of like importance. It is well known to ourselves and others that of a pair of portrait lenses which were selected, and for some time noted, for their absolute identity of action, especially as regards rapidity, one afterwards, which had been for over a year relegated to a different class of work from

the other, eventually became so slow by comparison with the performance of its twin brother as to prevent their ever again being employed in the capacity of producing binocular portraits. Seeing that a high-class, rapid-working lens involves the expenditure of a considerable sum, its retention in a state of pristine purity is, consequently, an object of importance.

Causes of Slowness.—There are two sources of deterioration of a photographic objective, and we may here explain that by 'deterioration,' in the sense now employed by us, slowness is understood. So long ago as the second meeting of the London Photographic Society, held on the 3rd of March, 1853, it was well recognised that some lenses worked much slower than others which had similar dimensions and working aperture, and some attempt was made to elucidate the cause. That the yellow colour of the glass of some of the instruments, as contrasted with that of others, was a prime factor in the slowness was acknowledged; but it seemed to be a moot point as to the part taken in such degradation of working by the Canada balsam with which the component parts of the front lens were cemented. Mr. Robert Hunt, one of the leading spirits of the then young Society, went so far on the occasion referred to as to say that it had been observed by Daguerre and others that by dropping upon the surface of a photographic lens a little of the purest oil of almonds, and then wiping it off again in as perfect a manner as could be done by a silk handkerchief, the attenuated film still left would necessitate a great prolongation of the exposure. From

whatever cause it may have arisen, neither we nor any one whom we have known to repeat this experiment have found it to yield the result mentioned. But that a film of Canada balsam of no great thickness will render photographic action sluggish is a fact admitting of no question. It has been found by Mr. George Shadbolt that in preparing two similar microscopic objects—the parasites of birds—for photographing, one of them being mounted in balsam and the other in glycerine, the former required an exposure of four minutes, whereas an equally good negative was obtained with the latter in one minute.

The great cause of lenses becoming slower is not the balsam used in cementing their elementary parts together, but the discoloration of the glass itself by the action of light. Lenses formed of dense flint glass are more liable to become deteriorated by the action of light than those of light glass. Why this should be so we are unable to say, although it has been surmised that, in some instances at any rate, it may have arisen from a trace of silver present in the lead which enters into the formation of flint glass. We well remember one lens of the 'rapid' type, which was exhibited before the (now) Photographic Society of Great Britain several years ago, by an eminent optician, as possessing a larger angular aperture, and consequently greater intensity of lighting, than any lens of a similar class ever previously produced. A few years afterwards, when inquiring of the maker the reason why a lens of such obvious utility had not been commercially manufactured, he said that the glass

of which that specimen had been composed, and which possessed a greater degree of density, had deteriorated to such an extent and become so yellow in colour that he would not jeopardise his reputation by allowing one to be issued from his establishment. He showed us the lens in question, and its yellow colour was quite noticeable.

When Mr. Thomas Gaffield, of Boston, brought the subject of the discoloration of glass before the British Association, at the Brighton meeting, in 1872, and showed examples of glass of a fine quality, which from being quite colourless had assumed a very sensible degree of deterioration on being exposed to strong sunlight under a mask for a brief period, it was felt that this deterioration, although of, perhaps, primary importance in such a case as the glass roofing of a studio, which was constantly exposed to light, would also affect photographic lenses, in which a degree of discoloration far less in amount would produce a greater effect in the prolongation of the exposure. To ascertain whether optical glass would follow the *rôle* of window and plate glass, we wrapped a piece of tinfoil round a lens in such a manner as to allow one half to be exposed, and this we placed where it could receive the beams of a September sun for a protracted period. Upon being afterwards examined by laying it on a sheet of white paper, the exposed half caused the paper to assume a decided hue of a character resembling yellow with a purplish tinge.

Cause of Discoloration of Glass.—Why glass changes it is not altogether easy to say with certainty. In the

case of plate-glass it is held to arise from the presence of manganese, which is added in the form of its oxide, and known as 'glassmakers' soap.' One theory of the action of the manganese is that in all kinds of window glass, and in some poorer sorts of flint glass, materials are used which are not chemically pure. There is usually iron present, the protoxide of which imparts a green colour to the glass. The addition of the manganese causes some of its oxygen to fly to the iron and convert its protoxide into peroxide, which imparts a yellowish colour to the glass; that, being complementary to the natural pink of the manganese, is neutralised and the glass rendered of a white colour. By the action of sunlight upon this glass the nice equilibrium between the oxygen of the iron and the manganese is disturbed, and sometimes a yellow and sometimes a pinkish colour is produced. Another theory is that the manganese is added solely on account of the facility with which it parts with oxygen, which consumes any impurities of an organic character or any oxidised, opaque, metallic particles. A singular fact in connexion with the discoloration of glass by the action of light is found in the further fact that by heating glass thus deteriorated it becomes decolorised.

Action of Light on Canada Balsam.—Now at this stage an element imagined to be of a conflicting nature has to be introduced; it is the Canada balsam. Painters are aware that white oil paint (carbonate of lead) when mixed with megilp, although pure enough while it remains exposed to light, assumes quite a yellow

appearance upon being kept in darkness, or, in the case of a painting, in a drawer for a few months or even weeks. In like manner it is affirmed that Canada balsam becomes bleached and colourless by the action of light, resuming its yellow appearance when kept in the dark. Here, then, are two angonistic forces to be kept under check. If the lens be exposed to strong light the glass has a chance of being discoloured while the balsam becomes decolorised; but if the lens be kept in darkness (except when in active use) the glass remains pure, while the balsam becomes discoloured. Now, while it is true that the discoloured white of the megilp oil painting will assume its original purity when placed in the sun for a few hours (unless it be a very bad case indeed), and, further, that coloured balsam will also become colourless, it is not the case that every kind of balsam changes colour; and we believe we speak within the mark in saying that for the productions of one optician which become deteriorated on this ground, those of twenty are unaffected. The balsam scare, therefore, need not prove a source of uneasiness to photographers, the more especially as by the means we recently indicated the old balsam may be readily cleaned away and its place supplied with a fresh and colourless sample.

Strong Light Discolours Lenses.—Of much greater importance is it that the lens be not subjected to any strong light, as it *may* cause a discoloration in the substance of the glass that cannot be removed. We do not here allude to surface stains in the form of

oxidised patches, which are often caused by damp and particles of dirt acting as nuclei, and which stains are capable of being polished out, but to a discoloration existing throughout the entire substance of the glass.

If an objective be employed for forming an image by the direct beams from the sun, such as is used in the solar camera, we advise that it be kept for that purpose exclusively, because of the facilities which the light has for acting injuriously upon it and rendering it slower. We would also state that of all classes of lenses which should not be employed in the solar camera, or for any other purpose associated with the transmission of bright light, those of the popular 'rapid' type stand at the head; for being formed of dense glass they are more liable than any others to undergo change. It is well, therefore, to keep them covered as much as possible when not in use. Portrait combinations and ordinary single achromatic landscape lenses, being formed of glass of less density, are better able to resist the influence of light; but even these should always have their caps replaced after being used.

CHAPTER XXVIII.

HOW TO ASCERTAIN THE ANGLE OF VIEW INCLUDED BY ANY LENS.

LET it be first of all understood that every class of lens having the same focus embraces the same angle on a plate of a given size. It is of no consequence what is the nature of the lens, or by what name it is called, whether single landscape, wide angle or narrow angle, rectilinear, symmetrical or portrait lens—one thing is true of them all—that if they be of similar foci the angle subtended on a plate of a certain number of inches will be alike in all of them. It is the focus of the lens and that alone which determines the angle of picture depicted on a plate of any given size. Some lenses may work sharper or quicker than others; but, though a mere simple spectacle glass be used, or even in the absence altogether of a lens, a small hole in front of the camera be employed for producing the image, the rule holds good.

In lenses of the distorting kind—such as the ordinary single combination with a stop in front—the compression of objects in proportion as they recede from the centre of the picture apparently militates against the accuracy

of the rule here laid down; but the difference in reality is so slight as not to demand attention, and the advantage they possess in this respect over the non-distorting class of lenses may in practice be ignored.

Wide-Angle Lens used for Narrow-Angle Views.—Let us narrow this question and apply it to special cases. Here are two landscape objectives of equal foci, but one is a wide-angle and the other a narrow-angle lens. If the latter cover a 12 × 10 plate and the former an 18 × 15 plate, but for various reasons the wide-angle one be only used for a 12 × 10, will there be any difference between the productions of the wide and the narrow angle lenses? Certainly not. Is there then any advantage in having a wide-angle lens for such a purpose as that in question? None whatever. But there is this advantage, that although it can do all the work that is done by the narrow-angle instrument (at the expense, however, of rapidity—for every gain is attended by a loss in some other direction), it can do more if required. It can be used on an 18 × 15 plate, whereas the other cannot.

Wide-Angle Lenses Necessarily Slow.—We have spoken of a loss of rapidity in connexion with lenses of wide angle. This is inseparable from their method of construction, their curves being deeper than those of the narrow class, and necessitating the employment of a smaller stop, for the narrower the angle sought to be included by a lens the greater may be its aperture in proportion to its focus and *vice versa*.

How to Measure the Angle of View.—The question may

now be asked—By what means can it be ascertained what angle of view a lens includes on a plate of any certain size? Before answering this we may make what to the majority of readers will be a self-evident statement: if a lens include on a plate twenty inches long an angle of view of 40°, on a base of ten inches the included angle will only be 20°.

Draw on a sheet of paper of sufficient size a straight line equal to the horizontal dimensions of the plate on which the negative is taken, twelve inches for a 12 × 10 plate for example, and from the centre of this line erect a vertical line equal in length to the focus of the lens. In the diagram the line A B is made the length of the

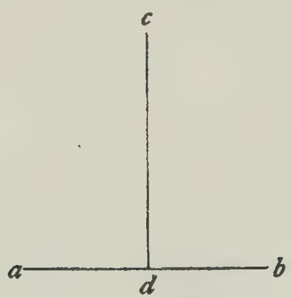

FIG. 49.

plate, whatever that may be, and the line C D is that which in a corresponding manner is made of the length of the focus of the lens. Now with a pencil draw lines from C (the lens) to A and B (the size of the plate), and the angle thus made with the pencil, or A C B, represents the angle of view included.

There are few cases of drawing instruments sold in which there is not in some form or other a protractor to be found by which angles may be measured. But some photographers may perhaps not have access to such an instrument, so we will now describe how such may make for themselves a protractor which if not so elaborate as those sold by the dealer in mathematical instruments will yet be as useful as the best of them, and possibly be more easy to employ. The following diagram repre-

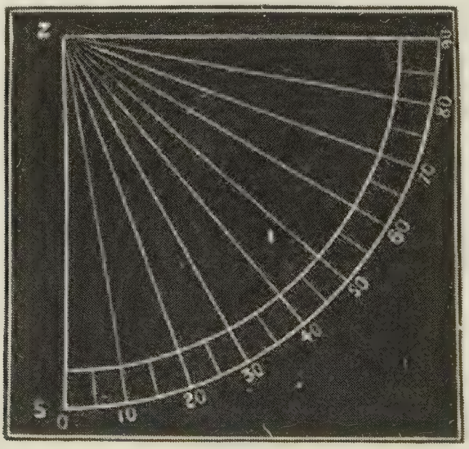

FIG. 50.

sents a protractor which includes an angle of 90°, and divided into nine equal parts, each part including ten degrees. These are further subdivided so as to permit five degrees to be read off. See Fig. 50.

To use this protractor; having laid down a base line

the length of the plate, having further erected the centre perpendicular line equal in length to the focus of the lens, and having also drawn the pencil angle lines already described, place the protractor down upon the lines thus drawn, the point Z being placed exactly on the point of the vertical line, and let the line Z S coincide with that drawn from C to A in Fig. 49. Observe now on what part of the protractor the other boundary line (that from C to B) falls, and the figures indicate the angle sought for. No calculations are required, and the results are obtained in the simplest manner.

CHAPTER XXIX.

REFINED FOCUSSING BY MEANS OF A TELESCOPE.

SOMETIMES occasions arise in which it is necessary to focus with extreme sharpness, even without a focussing screen.

At the Derby Convention in 1886, the author exhibited a camera to which was attached a pocket telescope to ensure absolute sharpness, and the conditions for the using of which we shall discuss.

Ground Glass Screens inadequate for absolute Focussing.—If the acme of perfection in focussing be desired, the image should be an aerial one, that is, not broken up by being projected upon ground glass which renders it difficult, if not altogether impossible, for any one to see it distinctly when employing a high magnifying power for such purpose. Just imagine the case if in a telescope a ground glass, no matter how fine its surface, were interposed between the eye-piece and the object-glass at the point of focus. The system of focussing now to be advocated and described permits of the dark slide being inserted into its place in the camera, its shutter drawn, and everything in readiness for the final uncapping of the lens, and all this without having determined upon the precise object at which the shot is to be made, or its distance from the camera, which in this

case may have a lens of twenty, thirty, or even forty inches focus, and be practically wanting in what is known as depth, and which entails the necessity of adjusting the focus upon the definite object to be taken, and not upon one either nearer or farther away.

Aerial Images.—A well-corrected lens, when directed to any scene, produces at its focus an aerial model of that scene, each portion of which presents the same relative distance to or from any other as do the same portions of the original. In a lens of short focus the whole of this aerial model is on a scale so diminutive and compressed that, except such portions as are close at hand, the distance relations between the others is too close to enable the eye to distinguish easily between them, and hence we say that everything beyond a certain distance is in equal sharpness, this 'certain distance' being nearer to the lens the shorter is its focus; but, conversely, the longer is the focus of the lens the greater is the separation of the component parts of the subject that is being examined, and the farther is that distance beyond which everything is practically simultaneously sharp. Five miles is a fairly long distance away, and so for that matter is one mile; but let an object at the greater distance be examined through a large telescope, the focus of which has been set for looking at something only one mile off, and it will be seen quite indistinctly until refocussing has been had recourse to; and when the five-mile object is made sharp a more distant object still will be blurry and indistinct until it in turn has been sharpened by refocussing.

Nature of a Focussing Telescope.—Let a little pocket telescope be procured, the object-glass of which is the same focus as that of the lens on the camera; such a telescope costs but little, and quite apart from the special use for it which is about to be described, it forms a most useful companion when one is away from home. One of such dimensions, with three draws and a leather-covered body, as will suit a camera of the average class employed in taking views on plates ten or twelve inches in size, can readily be obtained at a price under twice as many shillings, for high-class workmanship is not necessary; what is of importance is that the focus of the telescopic object-glass and that of the photographic lens must be the same. To prepare this telescope for camera use it is only necessary that one of the draws be made so easy as to slide in or out by a touch. The one most convenient for this is the second from the eye-piece end, and the requisite ease in drawing can be imparted by unscrewing that particular tube and scraping the interior of the short piece into which it travels, or by bending out the slots usually made in it to give it a springy smoothness of motion.

How to attach the Telescope to Camera.—On the top of the camera front to which the lens is attached, or from its side (it is immaterial which, so long as it does not interfere with other movements), projects a pin, on which the telescope fits by means of a small hole cut into the leathered-covered portion of the body at any convenient distance from the object-glass end. In the one shown at Derby this distance is three inches from it. The

same thing must be done with the eye-piece end of the telescope, the second sliding tube of which, by preference, must be connected in a similar way with the frame of the camera which carries the dark slide. It is of no consequence whatever how or where the outer end of the telescope is attached to the lens end of the camera, but care is required in determining the fixing of the other. It is effected in this way: Focus the camera lens on the ground glass on any moderately distant object with the greatest care, using a magnifying glass for this purpose, and noting the object that is in the centre of the field. Then, stepping the telescope on the pin in the front of the camera, direct it to the object forming the centre of the scene on the ground glass, and, having pulled out the eye-piece tube to its limit, focus sharply by means of the second tube, into which the second small hole has been drilled, and which will, or ought to, fall on some solid portion of the body or frame which receives the dark slide. Now insert the pin so that the expansion of the telescope is fixed at that point, and all the fitting is accomplished. It will now be found that, by racking the camera in or out, the telescope body will also slide with facility.

To Use this System.—We shall suppose that the object to be photographed is a ship rapidly proceeding out to sea, but that, owing to lighting or any other contingency, the precise moment for effecting the exposure is uncertain, and that the distance between ship and camera is ever increasing (or lessening). To watch the motions of the ship upon the ground glass would be

preposterous, because, when the proper moment for exposure arrived, the time occupied in removing the focussing screen and getting the dark slide inserted might cause a delay which would prove fatal to obtaining the right effect at the right instant, whereas, without the ground glass examination, one could not be quite certain of the object being in correct focus. But by the telescopic system, all that is necessary is to insert the dark slide and let the plate remain open, subject to the operation of the instantaneous shutter, watch the ship through the telescope, which is kept in sharp focus by the rack and pinion of the camera, and at the fitting moment press the pneumatic ball of the shutter, when the image will be secured with a degree of facility and accuracy of focus quite incapable of being attained in the usual way.

Application to Lenses of Various Foci.—The real use of this system is to be found when employing lenses of long focus and rather large aperture, but for experimental purposes we have also had one attached to a small camera in which we use lenses varying in focus from five to eight inches, and in accordance with an optical law we have made the object-glass of the little telescope adaptable for all lenses ranging between these foci. The law referred to is treated of in the chapter (page 154) 'On the Adjustment of Dissimilar Lenses,' but may here be summarised as follows: When two lenses of, say, ten inches each in focus are placed in contiguity, the focus is reduced to five inches approximately, but in proportion as they are separated so does the focus become

lengthened. Hence, by having two object-glasses of long focus each instead of one in the telescope, the inner one being in a small travelling tube moving inside, and capable of being run pretty close up towards the eye-piece, a considerable range, or rather variety, of foci is obtained, the precise amount of focal power being determined by graduations at the side of the slot through which the button projects by which the inner runner is moved. By a camera fitted with a little telescope of the nature described, we have, with a lens working with an aperture of *f*-4, selected one or more boys among groups which were playing at cricket on a common, and by following them with the telescope, focussing all the while by the camera rack, we have been able to 'snap' them off in individual sharpness, while, owing to the unusually large aperture of the lens, all their surroundings were more or less out of focus. But many applications of the system will, doubtless, suggest themselves to the ingenious reader.

Although we have never experienced any difficulty in procuring little telescopic object-glasses of any desired focus, yet it is conceivable that those at a distance from centres of optical industry may not be equally fortunate. Such may be interested in learning that in the case of an uncemented achromatic object-glass of a cheap telescope (which are almost invariably uncemented) a difference in the focus results by the insertion of a ring between the flint and crown lenses so as to separate them. The concave lens of the combination being nearer to the eye-piece than the convex or crown-glass

one, the farther apart they are separated the shorter will be their focus, being in this respect contrary to the effect produced if both lenses were positive, as previously explained.

If a telescope with two achromatic object-glasses be desired so as to permit, as in a case cited, of its being made to suit a camera to which more than one lens of a certain focus is to be affixed, the rule by which any definite focus of such telescopic objective may be accurately determined or ascertained is the same as that in the chapter just referred to, viz.: Knowing the focus of each of the two object-glasses, add them together, and subtract the distance of their separation; then multiply the two foci together and divide this last quantity by the first, which gives the precise focus of the two lenses when combined; the focus thus can be lengthened by increasing the separation, and by the above rule this can be done with unerring accuracy.

CHAPTER XXX.

LENSES OF JENA GLASS.

AT the present time this glass may be said to be still on its trial, and hence it may be premature to say much concerning its possibilities. Some samples of which the greatest expectation was formed, have been found not to stand the action of the atmosphere, although when encased in shells of glass of a more stable nature they would probably prove all that could be desired. Other samples, of whose stability little doubt is felt, are gradually beginning to supplant the time-honoured flint glass of English production. The Jena equivalent of crown glass in some cases possesses a high refractive and low dispersive index, thus rendering it possible to introduce new conditions in the correction of lenses, by which astigmatism is reduced and the field rendered flatter. Some examples of the lenses formed of the new glass will be given.

Schroeder & Stuart's Concentric Objective. — Messrs. Schroeder & Stuart patented, in 1888, a lens in which the radii of both front and back surfaces were struck from one centre, which would obviously make it of negative power if formed of only one piece of glass.

But this objective is composed of a plano-convex lens made of glass of a high refractive and low dispersive power, cemented to a plano-concave made of glass of a lower refractive power than that of the other, but of the same or higher dispersive power. Two lenses of this nature may be combined so as to form a doublet.

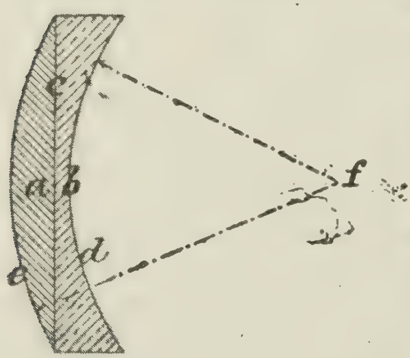

FIG. 51.

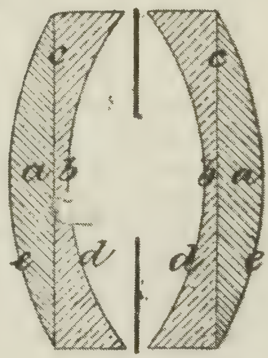

FIG. 52.

Fig. 51 is a transverse section of one of the lenses of the concentric combination made according to the patent, *a* being the plano-convex lens of high refraction and low dispersion, and *b* the plano-concave lens of lower refraction and the same, or higher dispersive power. They are cemented at *c*, and the surfaces *b* and *c* are portions of concentric spheres having their centre at *f*. In order to obtain a plane image throughout a large field of view, the radii of the external surfaces (*c* and *d*) should have a certain ratio to each other dependent on the refractive and dis-

persive powers of the glasses used. In practice it is found that the limits of the refractive power of the plano-convex are from about 1·59 to 1·61, the index being taken to be corresponding to the D line of the spectrum. Similarly the range of refraction for the plano-concave ranges from about 1·50 to 1·53. The objective may be used either singly, as in Fig. 51, or in combination with another similar lens, as in Fig. 52.

We were some time since permitted to examine a lens—one of a trial sort—prepared in accordance with the specification by Messrs. Ross & Co., and were impressed by its great covering power, the extreme oblique rays being focalised with a singular degree of perfection on a perfectly flat field.

Abbe & Rudolph's Triple Lens.—In this objective the front and back lenses are simple, that is, formed each of only one glass, and are meniscus in form (Fig. 53), their aberrations being corrected by a combination lens midway between them

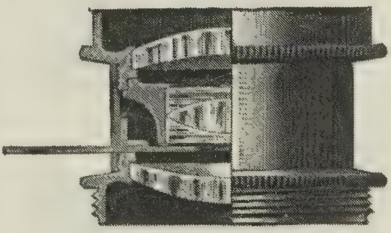

FIG. 53.

composed of three elements, the centre one being a borate glass cemented to two others by which it is protected. By this arrangement it is claimed to be possible to considerably reduce spherical aberration. It works with an aperture of *f*-16. The diaphragm is placed between the centre and back lenses.

Although we have credited Drs. Abbe and Rudolph with this lens, they being the patentees, yet, unfortunately, they had been forstalled by Dr. Schroeder, who, a few years previous, had published in *Astronomische Nachrichten* a description of an objective specially adapted for celestial photography, and which is practically the same as that just figured. Dr. Schroeder, we find, had tried both double, triple, and even quadruple elements in the central correcting dialyte, the exterior lenses of the combination being simple uncorrected menisci.

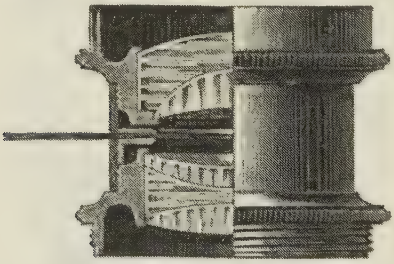

FIG. 54.

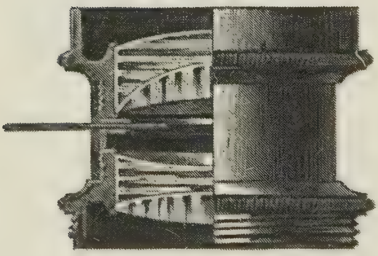

FIG. 55.

Rudolph's Doublets. — Dr. Rudolph has patented two doublets, one (Fig. 54) in which the front lens is a double cemented combination, and the back a triple combination, as shown in Fig. 55; the other having a front lens similar to the former, but with a back formed of only two elements, a bi-convex cemented to a biconcave. The patent specification contains several tables of ex-

amples of radii, thickness, and other measurements which it would prove impossible here to condense, but the principle of the construction of his various lenses, which are made by Zeiss, may be ascertained from the patent claim, which is, 'In a photographic objective, the combination of two distinct systems of lenses, each composed of single lenses cemented together, the positive element of one system having a higher, the positive element of the other system a lower, refractive index than the respective negative elements cemented thereto, and each system being in itself approximately achromatic.'

CHAPTER XXXI.

MOUNTS AND CELLS.

MANY years ago a French optician, Derogy, introduced a lens, now disused, but the mechanical features of which deserve more general recognition than appears to have been accorded to it. It was formed in several different sizes (three at any rate), these being the quarter, half, and whole-plate portrait lenses. In the normal condition these were lenses of good quality, suited for the different dimensions of plates.

Bayonet Joints for Lens Cells and Fittings.—Upon dissection and examination of these objectives certain peculiarities become apparent. First of all, the cells containing the lenses are not adapted to the mount by screws, but by means of 'bayonet joints,' there being two such fastenings fitted to each cell. The workmanship being good there is no chance of anything becoming unfastened. On removing the front cell, which is done by a quarter of a turn of the hand, it is found to contain the means for adapting still another cell, the position of which will be nearly midway between the front and back lenses. The object of this third cell-receptacle is seen when, upon opening a small circular morocco case, which

is packed in the hood of the lens, two cells, each containing a supplementary lens—one concave and the other convex, both being achromatic—are disclosed neatly fitted in appropriate receptacles. Either of these can, with a quarter turn of the hand, as before, be transferred to the vacant place in the mount, and thus serve to modify the focus.

Lengthening or Shortening the Focus.—The real efficiency of the system will be seen from the following measurements which we have made of the *equivalent* foci of the one such lens in our possession when subjected *seriatim* to its several modifying influences:—Premising that the lens now being described is one of the smallest which were made, namely, the quarter-plate size, and that the diameter of the front and back elements is slightly under one inch and three-quarters, in the combined form as a double portrait-lens the equivalent focus is seven inches. The insertion of the cell containing the concave achromatic, and upon which is engraved '*Lentille pour faire plus grand*,' lengthens the equivalent focus to nine inches; while the substitution for it of that containing the convex achromatic, and which bears the inscription '*Lentille pour faire plus petit*,' shortens the focus to five and a quarter inches equivalent, or three and a half inches back, focus. But the front lens is also adapted for being used alone, for which purpose it is transferred to the place of the back combination, previously removed from its position, giving a focus of eleven inches. This, however, is not all, for by employing the front and the concave together a

focus of seventeen inches is obtained—the substitution of the convex for the concave in this relation giving a focus of eight inches.

Here, then, are great capabilities condensed in a small space. In this one objective we have foci to the following extent:—Five and a quarter inches, seven inches, eight inches, nine inches, eleven inches, and seventeen inches. We have an idea that this combination has long ceased to be manufactured; but it is probable that the causes which led to its having fallen into desuetude are now removed, and we describe it as containing merits to which manufacturers might well pay heed. Incidentally we may state that one of the combinations formed is that which, after many years' experiment, has been found by Professor Woodward to be best adapted for use with his solar camera as an objective. The combination alluded to is that in which the convex supplementary lens—an achromatic meniscus —is utilised for the purpose of shortening the focus of the portrait objective.

Distance between Lenses should not be Arbitrary. — It does not follow that in the case of a combination lens the distance at which they are set apart in the mount is the best for every purpose. The optician has to make a compromise, and secure a balance of advantages. That distance at which flatness of field is best attained *may* be attended with flare, while an increased angle of view may, under certain circumstances, be secured without any serious loss by setting the lenses much closer together. The most generally useful mount for a lens of

this class is one in which each lens is set in a short supplementary tube, capable of being drawn out from the common centre, so as to increase or shorten the distance between them at will. When the lenses are separated to the maximum extent, the field will be flat even to the verge of astigmatism with a large aperture; while, in proportion as they are made to approach each other, so does the area of illumination increase, this, however, being attended with roundness of field. Hence, by adopting suitable precautions in the separation, a doublet lens may be made to act either as a wide or narrow angle objective. The expediency of adopting a mount of this kind is, however, open to question, as there might not be one out of ten who would know how to use the power aright were it placed in their hands.

Distance of Stop in Single Lenses.—A very sensible advantage may frequently be derived by the power of adjusting the distance between the stop and the lens in the case of a single landscape objective. It is well known that with all such lenses, especially those of a plano-convex or only slight meniscus form, the farther the stop is from the surface of the lens, the wider may be the aperture in such stop. This, however, circumscribes the field of delineation. By placing the stop nearer to the lens, two advantages are secured. First, the lens will cover a much larger plate, and, secondly, the distortion that is so common to landscape lenses becomes minimised; for, as we have shown in a previous chapter, the nearer the stop is to the optical centre of a lens, the less

is the distortion: but this approximating of the diaphragm to the lens necessitates a smaller stop being employed than when a greater distance intervenes between them.

Cell-bound Lenses.—It is of vital consequence that a lens be not set in its cell under conditions which give great pressure to any part of its substance. A delicate, well-constructed lens may have its good qualities disturbed by being forced into a tight cell which is burnished down upon it, thereby giving considerable pressure. The presence of this pressure is readily ascertained by placing the lens in a beam of polarised light, and examining it by an analyser, by which the strain on the glass will be shown. The effect of this is precisely as though the lens had been made of badly annealed glass.

Aluminium Mounts.—The weight of the brasswork of lenses is often far in excess of what is required for rigidity. By adopting *papier maché*, ebonite, or aluminium, an important saving to the wear and tear experienced by the photographer would be effected. It was at one time objected to aluminium that it was expensive. This was true to some extent, although not so much so as to render its applicability to a photographic lens of great importance in this respect. But it is now the case that owing to the demand which has arisen for this metal, its price has been reduced to that at which copper is now sold. As the specific gravity of aluminium is about 2·56, while that of copper is frequently 8·96, the great gain in lightness will be apparent.

Some makers, notably in America, have begun to discard brass for the diaphragms of their larger lenses, adopting ebonite or vulcanite instead, to the great advantage of the users. It only remains that this measure of reform shall be made to permeate the other portions of the mount to have an improvement far exceeding that which was inaugurated by the introduction of the leather cap in lieu of the heavy brass cap which it supplanted.

By the apparent paradox of making use of heavy glass the opticians are now able to give us lenses small in bulk and comparatively light in weight, so far as concerns the mere glasswork of the objective. It now devolves upon them to effect a similar measure of reform in the mounts of the larger of the portable form, such as those exceeding one and a half inches in diameter.

Dimensions of Flange Apertures.—It is much to be regretted that up to the present time no really universal system of diameters of apertures and screw threads in lens flanges has yet been adopted, notwithstanding the efforts of committees of Congresses, Conventions, and Societies to bring about so desirable an end. A practical outcome of the chaos that still prevails is, that three or four lenses may be purchased from as many different leading opticians, and although the screws on these might have so easily been absolutely as they are nearly identical, not one of them will interchange with the others in the flange. This for many years has been a sore grievance with users of lenses.

A Universal Lens Adapter.—Pending the adoption of some system on which all makers will agree, we give here a method, originated in France, by which lenses having various flange apertures can be quickly adapted in succession to any camera.

A series of discs of ebonite or thin metal, one for each lens, is provided. They are all of equal diameter outside, but the aperture in each is such as just to allow the screw of the mount to pass easily through. The flange, which is smaller than the disc, is now screwed on the mount and keeps the disc firmly fixed. The hole in the camera front is smaller than the disc, which, when placed over it, entirely covers the aperture. Three guide pins, or, by preference, a round recess in the camera-front, ensures the lens being centrally attached, and a turn-button at each side secures it firmly to the front.

This method is equally useful for the studio as for the field camera. It permits of one lens being changed for another in a very brief period of time, and saves the trouble of having a separate camera front for each lens that is likely to be used.

Lens adapters constructed on the iris diaphragm system is another French idea. They grip a lens with a closeness sufficient to prevent the admission of light, but the hold taken of the lens by the thin edges of the iris blades is rather too slender to ensure the lens against dropping out at an inopportune moment.

CHAPTER XXXII.

LENS GRINDING.

ALTHOUGH, as we have stated in the Preface, this work is intended for users and not manufacturers of lenses, yet may there be some among the former who desire to know how lenses are ground and finished.

Selection of the Glass.—As all dealers in optical glass supply it of the requisite degrees of refractive and dispersive indices, no trouble now arises in procuring it. But having been obtained, it is necessary to subject it to careful examination for internal defects which would otherwise only be discoverable after the labour of grinding and finishing the surfaces had been undergone, and the labour thus wasted.

Imperfect annealing demands primary attention. This defect, where it exists, is readily discoverable by examining the glass by polarised light. Let A (Fig. 55) be a lamp, C ten plates of clean glass bound together at the edges, and E a Nicol prism. The light from A becomes polarised when reflected from C at a suitable angle; and when any object, D—in this case the slab of glass undergoing examination—is placed in the path of the reflected ray, any internal homogeneity in the glass

arising from imperfect annealing is rendered plainly visible by rotating the analyser, E. Incidentally we may observe that by this means defects in finished lenses can also be discovered. For example, an otherwise perfect

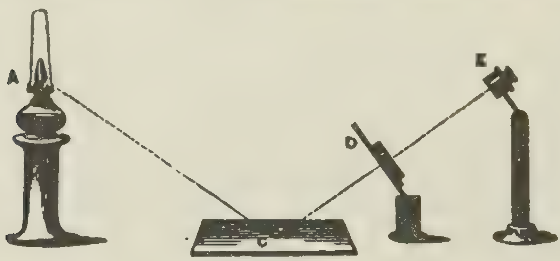

FIG. 56.

lens, if subjected to undue pressure in its cell, will show lines or patches of opacity when subjected to this test.

To effect the conversion of a piece of plain glass into a lens is a class of mechanical work demanding no exceptional degree of skill, although care is necessitated. Where genius is required is in the determination of the curves to suit the special requirement and of the glass best adapted to the purpose. An able mathematician can, as the result of his calculations, send to the manager of a lens-grinding establishment a formula or specification for a lens as to which he can predicate before the work is commenced everything as regards its capabilities and performance. This, however, belongs to the 'fine-art' department of the business and to the higher mathematics. We must here confine ourselves to the more material aspects of the construction of a lens.

Density influences Curvatures.—The density of the glass determines the curvature requisite in making a lens of a definite focus; but the following rules and explanations will serve to afford an average or general idea of the relation between focus and curvature. On the supposition that we are dealing with crown glass: if a circle be made on a sheet of paper with any opening of the compasses—say three inches—and a portion of this circle be cut off by a straight line, such portion will represent a plano-convex lens of three inches radius, and its focus for parallel rays will (assuming the convex surface to be directed outwards) be nearly upon the line of the circle opposite to the lenticular slice. This is more tersely expressed in treatises on mathematical optics as follows:

Rule for Finding the Principal Focus of a Plano-Convex Lens.—When the convex side is exposed to parallel rays the focal distance will be equal to twice the radius of its convex surface, diminished by two-thirds of the thickness of the lens.

Rule for Finding the Principal Focus of an Equally Double-Convex Lens.—The focal distance is equal to the radius. In the drawing which we have imagined above if, instead of the portion of the circle having been separated by a straight line, a curved line of the same radius as the circle had been employed, the lens formed would have come under this category, namely, equally double-convex, and its focus would have been approximately in the centre of the circle, or three inches.

Rule for Finding the Focus of a Double-Convex Lens of Unequal Curvatures.—Multiply the radius of one surface by the radius of the other, and divide twice this product by the sum of the same radii. This last lens is usually designated a 'crossed' lens.

In the case of a meniscus with parallel rays we must divide twice the product of the two radii by their difference, and the quotient will be the focal distance required.

These rules must not be considered absolute, for with every different sample of glass there may be a departure from them, and, in some cases—*e.g.*, dense flint—the departure will be very considerable; but with ordinary crown or plate glass they are, probably, as near as can be framed in popular language.

Grinding Tools.—Having determined upon the diameter and curvature of the lens to be made, the first thing to do is to obtain grinding tools of the radius of curvative required. They consist of a pair—namely, a convex and a concave—and can be purchased of any radius from those who make a speciality of this department of business; but an amateur will, doubtless, prefer to make them for himself. To do this he must make two templates of thin sheet brass or zinc (Fig. 57), by turning one piece to exactly three inches in diameter, assuming that a radius of three inches is to be employed; the other piece to have a hole of this diameter cut in it, and afterwards divided into two pieces. To make a concave grinding tool: provide a thick and substantial piece of brass or gun-metal in the form of a chuck, and with a

suitable turning-tool hollow out the end so as to fit the curvature of the round template. This may necessitate several trials if the amateur be inexperienced in the use of lathe tools. A second piece of brass is now turned in the same way, but so as to be the exact counterpart of

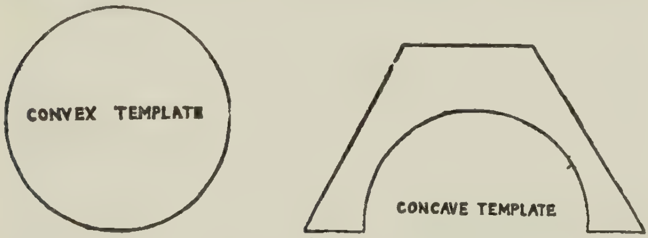

FIG. 57.

the preceding; that is, its outer end must be rounded, and this curve must be gauged by the hollow template. Both tools having been finished by the lathe tool as well as possible, they are next ground one upon the other by friction, with the interposition of a little fine flour emery and water until they fit each other with great nicety.

FIG. 58.

To prevent waste and save labour, glass-makers now supply the material moulded appropriately to the form the lens ultimately assumes; but where the raw material is in the form of a flat slab, it is cut into squares, each of which is 'shanked' to a circular form by means of a pair of shanks, as shown in Fig. 58, these being

made of soft iron, and procurable from all dealers in opticians' requirements.

The glass having been nibbled or 'shanked' to a round form is cemented by pitch or sealing-wax to a suitable handle, and is rough ground, either on a grindstone or in an iron mould with coarse sand, until it is nearly the shape required. For small lenses this may be effected in the turning lathe with a sharp steel cutting tool, which must be kept constantly wet with spirit of turpentine, benzoline, or one or other of several liquids of a similar kind, which have been found to answer the purpose equally well. It is desirable that a flat piece of glass, B, be interposed between the handle A and the lens C to prevent marginal errors in grinding. In either this or the rough-grinding method the template must be occasionally applied as a means of ascertaining progress. It being desirable to save the brass tools as much as possible, the more effectively the first

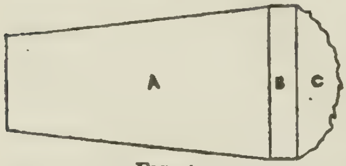

FIG. 59.

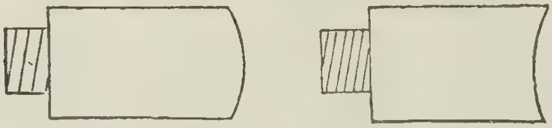

FIG. 60.

grinding is done in the coarser tool the better will it be for the chances of the finishing tool preserving its form unimpaired for a long period. Fig. 60 shows a convex

and a concave tool ready for insertion in the turning lathe.

Grinding the Surfaces.—Grinding proper is effected by means of emery, of which several grades are employed. In large cities opticians' emery is a commercial article. Those who prefer to make it for themselves may do so by taking a quantity of flour emery—say a pound—and placing it in a clean jar. To this add water and stir it about until it is all wet and of a pasty consistence. Now add water to fill up the jar, stir the whole contents well round, and, after waiting for a little till the heavier particles subside, pour off the water, in which is mixed up the lighter portions, into a second jar, which fill up with water and stir vigorously as before, pouring off the water, after five minutes, into a third jar. This is repeated, a longer time for settling in each case being given. The result of this washing process is that while in the first jar the deposit consists of the coarsest portions of the emery, the deposit becomes finer and finer as the washing is allowed to proceed, till at last the water holds in suspension only the very smallest atoms of the emery, which, when precipitated, forms the finest emery capable of being procured.

To smooth the roughly ground surface of the lens the coarsest of these deposits of emery is first employed, mixed, of course, with water. When upon examination with a magnifier the surface is homogeneous, the grinding is repeated with a finer, succeeded by a still finer, grade of emery, until at last the convex surface of the glass is so fine as to present the appearance of being

ready to burst into a black gloss. At this stage the operation with the emery terminates. It need scarcely be said that in the grinding with the various grades of emery careful washing must be resorted to between each, and that the grinding with any one class of emery must be continued until every mark made by its predecessor has been removed. Also, in course of the grinding it is well that the counterpart of the tool be applied, with a little emery and water, so as to ensure its being kept in shape.

Polishing the Lens.—To impart a final polish we have seen several methods adopted. One, and the most primitive, is to cement on the face of the grinding tool a piece of textile fabric of a fine nature from which the nap has been removed by a hot iron. Some employ woollen cloth, others fine linen, and in some instances paper. It is cemented on the face of the tool by pitch or other cement, the counter tool being employed to preserve the curve. Rouge, a mixture of rouge and putty powder, or, not unfrequently, putty powder alone moistened with water, is employed to give the final polish. When the finest surface possible to be obtained is desired, instead of polishing upon cloth or linen the tool is faced with pitch. This is applied by warming the tool and then rubbing over it a piece of pitch, which melts and coats the surface in a uniform manner. It is spread more evenly by the application of the counterpart tool. A little rouge or putty powder is spread over the surface and moistened with water. On applying the surface of the lens to this with rapid friction it immediately receives a fine black polish.

Putty Powder.—The best way to make putty powder for this purpose is to dissolve tin in *aqua regia* and precipitate by diluted ammonia. Wash the peroxide in several changes of water, and, after drying, expose in a crucible to a low white heat, by which the particles acquire the property of polishing quicker and better. Owing to the white colour of the putty powder many prefer to mix with it a little rouge or crocus—not alone to modify its polishing properties, but also to enable it to be seen when on the cloth. The polishing powder must not be too wet, but sufficiently so to take a partially glazed appearance from the action of polishing.

Edging and Centering.—The edging of the lens is effected by cementing it upon a chuck, and while rotating in the lathe the reflection of the flame of a candle is observed. If it remain quite steady all is right; but, if not, it must be shifted slightly before the cement hardens until it do so. A piece of copper or brass well supplied with emery and water is then applied to the lower edge, an even pressure being given until the edge is smooth and the lens quite round.

Blocking Lenses.—When lenses are not large and are to be ground to shallow curves, a considerable number may be cemented on a block and operated upon simultaneously. In this way upwards of two dozen may be ground and polished in the same time that one would take. For grinding the commoner class of lenses, such as spectacle glasses, machinery is employed in connexion with the block system.

Specimen Lens Curves.—It would be foreign to the object of a work like this to give formulæ by which the curves of lenses formed of the many different kinds of glass now procurable may be ascertained, but it may not be out of place to give the curves (supplied through the courtesy of the present head of the firm), of a fine specimen of the No. 2 wide-angle lens of Dallmeyer, of the form shown on page 44, Fig. 18, made for us in 1865. Measuring from the diaphragm, the radii are—

1. − 5·253.	4. + 4·306.
2. + 1·46.	5. − 4·306.
3. − 1·46.	6. + 2·2.

The diameter is 2 inches, and the focus 8½ inches. It is made of Chance's glass. Soon after receiving it we found that it would bear a working aperture very greatly in excess of that intended by the optician, and for over twenty years we have used it for portraiture, with an opening of *f*-8. When stopped down it covers 10 × 8 easily.

CHAPTER XXXIII.

OPTICAL CONTACT—CEMENTING LENSES.

THE fewer the reflections in or connected with a lens the better, because the invariable tendency of these is the fogging of the plate. Some lenses distribute the reflections all over the plate; in the case of others a concentration takes place upon the centre of the negative. The former is not good, and the latter is highly objectionable.

What we here mean by reflections will be better explained by a demonstration. Take a portrait lens and step with it into a darkened room. Light a candle and place it at a distance of a few feet; then hold up the lens in the line of the candle light, when a repeated duplication of the image of the flame will be seen, some of these images being erect, others inverted.

Reflections Reduced by Cementing.—Now, seeing that the fewer reflecting surfaces there are in an objective the fewer will be the number of these reflected images, of course, it follows that the multiplicity of such surfaces is an evil, and for this reason opticians have sought to make the inner surfaces of achromatic lenses 'contact curves' as far as possible. The reason for this is

obvious: if these inner surfaces be concentric as regards curvature, it is only necessary that they be placed in *optical* contact to ensure a nearly total elimination of the reflections that would inevitably arise were the contact between them merely mechanical instead of being optical. To secure the latter, all that is necessary is to interpose between the two concentric surfaces any clear fluid—such as water, oil, or varnish—when the interior surfaces that could previously be seen by looking down upon them immediately disappear, and the lens appears to be formed of one homogeneous piece of glass.

Cementing by Balsam.—Of the various substances employed in the cementing of achromatic lenses, that which is most generally preferred is Canada balsam; for it is easy of application, possesses the requisite degree of transparence, and dries quite hard. There is a well-grounded objection to the employment of this substance for large telescopic object-glasses, because the expanding ratio of flint and crown glasses being different, they will be affected by thermal influences, which would cause a strain owing to the two unequally expanding bodies being securely cemented together. To obviate this a permanently fluid body—*e.g.*, castor oil—is recommended in preference to balsam for lenses of this class.

The photographer who wishes for ocular demonstration as to the advantages arising from cementing a lens can obtain it in the following manner:—Provide two clean pieces of glass, such as quarter-plates, and,

holding one of them in a level position, allow a drop of oil to fall upon it. Now lay the second plate on the top of the other so as to cover and flatten out the drop of oil. Observe how transparent the glasses have become by the cementing of the inner surfaces in the manner described. Wherever the oil touches both surfaces optical contact is secured. The experiment just described serves to demonstrate the difference between optical and mechanical contact, and also to show the brilliancy arising from the cementing of two surfaces of glass.

Almost without exception the front lens of the portrait combination and both lenses of the 'rapid' class of objectives are cemented; but the cement not unfrequently undergoes changes and vicissitudes by which the performance of the objective is seriously damaged. We shall here describe the nature of some of these changes and the means of cure.

Arborescent Markings in Balsamed Lenses.—Occasionally, after a portrait combination has been some time in use, an arborescent growth, commencing with a single, delicate, leaf-like form, appears at one side of the front lens, and gradually spreads inwards. If the balsam has been very thin when applied, this arborescence spreads over a large portion of the surface. One of the finest examples of this defect occurred in the back lens of one of our 10 × 8 'rapid' objectives which remained good for about four years after being made, and then had a beautiful mass of shrubbery growing all round the margin. This increased to such

an extent as to leave only a small clear spot—the size of a threepenny piece—in the centre. This is, perhaps, the most prevalent form of defect in the cement of a lens.

Discoloration of the Cement.—Another, which also makes its appearance after the lens has been in use for a few years, consists in a discoloration of the cement. All round the margin the lens is found to have become of a yellow colour, which, although at first pale, afterwards becomes more decided, and not unfrequently assumes a green hue. Eventually the lens becomes so slow in its action as to be cast aside, and to have its place supplied by the instrument of another maker. In all cases of this character which we have had an opportunity of examining, the defect in question invariably arose from the lens having been burnished (or screwed) into its cell before the balsam had been allowed to harden, in consequence of which an action had set up between the balsam and the brass cell surrounding the lens, resulting in a slow decomposition of the latter, which eventually coloured the balsam.

There are some kinds of balsam which acquire a yellow colour through age; but we are not aware, in our own experience, of any thin film—such as that which forms the cementing stratum of two lenses—ever having become discoloured by light to an extent that could be appreciated. On the contrary, the tendency of light is to bleach it. Time, however, and exposure to the atmosphere certainly imparts a yellow colour—a fact well known to those who have prepared trans-

parent paper by the agency of Canada balsam. It is also known to microscopists that sometimes slides which have been prepared with balsam have, after a few years, acquired a yellow tint somewhat similar to that which results if an excess of heat be applied in the preparation of the slide.

To Remedy Defective Cementing.—When a defect in the cementing of the lens is observed, or when a discoloration is suspected owing to a lens working more slowly than it did originally, and which discoloration may be detected by laying the lens upon a sheet of white paper and noting its appearance, the first stage in the remedying of the defect—supposing the photographer elects to cure it himself instead of sending it to an optician—consists in removing the lens from its cell into which it is fixed, either by the edge of the cell being turned over its margin or by a screwed ring.

On its removal from the cell, the lens is placed in a saucepan on the bottom of which is laid a small piece of wood to prevent the contact of the glass with the metallic bottom. Slightly lukewarm water is now poured in to a height more than sufficient to cover the lens, and heat is gently applied until the balsam has become so soft as to permit the lenses, when manipulated by the fingers, to be slidden one from the top of the other. When this has been done, the water is wiped off and the lenses allowed to become cold. Ether or collodion is now poured over each surface, and gentle friction with a soft cloth applied. By this means the old balsam is dissolved and entirely removed. Oil

of turpentine or benzole answer a similar purpose as a solvent. The cleaning of the surfaces is finally completed by means of soap and water.

Some have recommended the use of the carbonates of potash or soda as a solvent for the balsam ; but these are bad, on account of their action on the glass.

Cementing the Surfaces.—When quite clean, and wiped dry by means of wash-leather, lay the flint glass on a sheet of paper, concave side up, and deftly apply a large drop of the finest quality of Canada balsam to the centre, taking care that it is free from air bubbles. Arrangements must be made for keeping the lens quite warm during this operation. Now lower down upon it the contact surface of the crown glass, and by gentle pressure guide it so as to cause the drop of balsam to expand equally outwards until it oozes slightly out at the margin. Next lift it up, and by means of a long piece of soft string tie the two together, crossing and recrossing the string in every direction. This ensures their being kept in a central position. Heat is now gently applied by laying it on the hot plate of a warm but not superheated oven, until upon removing the lens and testing the balsam which has oozed out at the edges it is found to be hard. Then, having allowed the lens to cool slowly, remove the string, and clean thoroughly with ether or benzole. The lens will now be found to have become rejuvenated.

CHAPTER XXXIV.

SELECTION OF LENSES.

Form of Lenses for Enlarging.—For an enlarging objective with the solar camera, in which the source of light partakes more of the nature of a point than what we have been considering, the construction of the objective may partake of a far wider range and be of a more diversified character than any of the others. We have seen images similar in dimensions produced from a test negative in which the objective was composed respectively of a portrait lens, a 'rapid' combination, and an achromatised meniscus. It was not only a difficult matter to adjudicate upon the respective merits of these pictures, but experts present at the time and having before them examples produced by each system of objective were found to have arrived at varying conclusions respecting their relative merits. In conversation with the late Dr. van Monckhoven, who had bestowed much attention upon the subject, that gentleman gave it as his opinion that the best of all objectives for the solar camera would yet prove to be a single achromatic. Previous to that time he had, in his work on *Photographic Optics*, in 1866, in the portion in which

he describes his enlarging solar camera, spoken of its objective as having the 'external form of Ramsden's eye-pieces placed on pocket telescopes, but constructed on the principles of M. Petzval's doublet.' That the doctor had altered his opinion subsequently to writing this is apparent from the fact that to none of the objectives manufactured by him at a later period does this description apply, and we have seen several. Woodward, of Baltimore, who has constructed more solar cameras than any other, makes the objectives of best 'solars' of three achromatic lenses, the front and back being similar to those of the ordinary portrait combination, but having the focus shortened by the insertion of a third meniscus achromatic lens between them.

Enlarging Portraits.—If the subject to be enlarged is a single portrait, say of *carte* size or a little larger, then will a *carte* or other good quarter-plate portrait lens be found to be the most suitable. It is of the greatest consequence, however, that the back lens of the combination be placed next to the negative, otherwise will the definition and flatness of field be inferior. There will be little or no necessity for using a diaphragm in the lens, as the area of sharpness when employing full apertures will be quite sufficient for the intended purpose.

Landscapes.—But in the case of a landscape or a group, some members of which are near to the margin of the plate, it will be requisite either to make use of a diaphragm, so as to ensure marginal definition of the highest class, or to employ a lens of longer focus. The solar focus of a lens is not its focus when used for

enlarging, more especially to the extent of only a few diameters, and hence it should be borne in mind that the focus being longer when thus employed its covering power is extended. A combination lens of the 'rapid' doublet type will be found excellent in the case of a landscape, in which, unlike a portrait, the marginal definition must equal that of the centre.

If time of exposure be of no consequence, then will an achromatic of plano-convex or slight meniscus form answer well the purpose of an enlarging lens. But it is necessary that a rather small top be employed, that it be situated at not less, but preferably more, than the diameter of the lens from its flat surface, and that the convex surface of the lens be placed next to the negative. There will be a residuum of distortion when employing such a lens, but in the case of a landscape or group it will not be discoverable in the large picture which results from the operation, and this being so, nice theoretical considerations concerning rectilinearity may be placed to one side. But if any curvature of a marginal vertical straight line—as in the case of a building—be discoverable, this may be reduced by removing the diaphragm and placing it closer to the lens. This applies only to single landscape lenses, and only then if the subject be an architectural one, the vertical lines of which extend to the margin and show indications of being curved.

In an objective employed in enlarging one is apt to be deceived as to its focus. This may be illustrated by an example. Suppose that the solar focus (equivalent)

of the enlarging objective be six inches, the distance between the centre of the lens and the negative to be enlarged would be six inches practically, were the screen on which the enlargement is projected at an infinite distance. These two, the negative and the screen, represent the anterior and posterior conjugate foci of the lens. But as such a position of the screen is impracticable it must be brought nearer, and as there is a strict relationship between the conjugate foci, the nearer the screen is made to approach the objective the further must the negative be removed from it. When the screen has been brought so near as to show the image of the same dimensions as the negative, then if a careful measurement be made, it will be found that the lens has now a focus of twelve inches, or double that it possesses for distant objects. The anterior focus of the lens, represented by its distance from the screen, is now found to have been reduced from infinity to twelve inches also.

Stereoscopic Lenses. — For securing instantaneous stereoscopic pictures of a well-lighted outdoor scene the great majority of subjects will be amenable to the action of a single lens of about six inches focus. This admits of the employment of a diaphragm sufficiently large to permit the usual class of subjects, including seaside groups, boats, &c., to be taken in a quasi-instantaneous manner. But if the very best effects as regards rapidity of exposure are desired, it then becomes necessary to employ a pair of portrait combinations, used without any diaphragm. Of these the finest effects will probably be obtained with a *back* focus of from five and a half to six

and a half inches, as this gives a more uniformly lighted picture than when an objective of short focus, such as three and three-quarters inches back focus, is employed, as was frequently the case in those days when instantaneous stereoscopic photography was prevalent.

For indoor groups and scenes it is probable that the regular stereoscopic portrait combination of short focus cannot be surpassed, or even equalled, for general utility. Its small diameter and short focus give it a great penetrative range, while its large 'angular aperture' enables it to be worked with great rapidity. Although on this account we advise its employment in preference to any other in a room in which it is desired that a scene or group be taken with a short exposure, we are strongly of opinion that for outdoor purposes it is not to be commended, unless the subject to be taken be at no considerable distance from the camera.

Lenses for Direct Portraiture.—For *children's* portraits it is necessary that the lens has a large aperture, seeing that they must be taken with the briefest of exposures. To this end a Petzval portrait combination will form the most useful lens, this being employed with a concealed pneumatic shutter. For adults, or where the same rapidity is not necessary, either a portrait lens of as long a focus as possible, or a cemented rapid doublet may be used. If the studio is badly lighted, the former will prove the more useful. If a large head and bust be wanted, and the light permit, a single landscape lens, working with a large aperture, will give soft and harmonious pictures.

P

Lenses for Pure Landscape.—Ordinary landscapes in which architectural subjects do not form a chief feature are best taken with a landscape lens—that is, a single achromatic. This class gives bold, crisp definition, this brilliancy of the image being due to the simplicity of the form; for, as we have shown in a previous chapter, the presence of a second lens in a photographic objective causes the formation of flare, which, when not confined to one central spot, becomes diffused over the negative, thus leading to a want of vigour in the shadows. This class of lenses, when employed for pictures of medium dimensions in which the included subject is of a somewhat small angle, is capable of being used with a stop sufficiently large to permit good negatives being obtained with an exposure of a fractional part of a second.

Groups.—When a group is to be taken, either in a studio or in a dull light out of doors, one of the 'rapid' class of lens with an intensity of from *f*-7 to *f*-13, according to circumstances, will be found to be the most useful. This lens also forms the best objective for large portraits in the studio, which it produces of more harmonious quality than a large portrait lens could possibly do.

Copying Portraits.—In the copying of a portrait it is probable that photographers will invariably use the portrait lens they commonly employ. This class of work falls quite within its scope; but, as the majority of operators first focus the picture and then insert a small stop to work with, we caution them that several otherwise good and useful portrait lenses, as well as some specially constructed for copying, have their focus altered

by the insertion of a smaller stop to work with than that by which the focussing was effected. This is not always the case; but, as it is sometimes so, it is a wise precaution to use the full aperture of the lens for making the general arrangements and having the focussing effected, and then, after inserting the working stop, to take a final look at the image on the ground glass and ascertain the state of its sharpness by means of a magnifying-glass, observing whether by slightly turning the pinion the definition is not capable of being improved. Observe this: that when the copy is required to be larger, or on a larger scale, than the original it is necessary that the lens be turned 'end for end' so as to have its back lens nearest to the picture to be copied.

Maps or Charts.—When the subject to be copied is a map or chart it is absolutely necessary that a non-distorting objective be employed. A lens of the 'rapid' class is most advantageous for this kind of work.

Large Micro Objects.—If the class of work required to be reproduced on a scale of magnification be flies or insects of moderately large dimensions, a quick-acting locket lens will answer the purpose better than a properly constructed miscroscopic objective of the same focus, as the former has its chemical and visual foci coincident, whereas the latter has not.

Architecture.—Architectural work can be produced equally with 'rapid' as with wide-angle lenses, provided these be of a non-distorting class. Distortion, as here meant, implies the curving of lines near the margin of the picture which are straight in the original.

CHAPTER XXXV.

ON THE CURE OF EXISTING DISTORTION.

Distortion of Curvature.—A single landscape lens, more especially when made to take in a wide angle of view, gives to all straight lines near the margin of the view an offensive curvature to the image, which becomes increasingly great as these recede from the centre. In ordinary landscapes this is quite immaterial, unless when such happen to be bounded at either side by a very tall building which extends considerably up the margin of the plate ; in portraits or groups the distortion of curvature is also not of a nature that can be discovered. But quite different is it when the subject of the photograph is architecture or a map or plan. For these a non-distorting compound lens should be used, but we are now dealing with the fact that such has not been employed. Here, then, we are confronted with a negative in which what should be straight lines towards the margins are bent like the sides of a barrel, and the question is, How to cure it ?

The first thing to be done is to make from the distorted negative a transparency by superposition on the same sized plate. If care be taken to have negative

and plate in perfect contact throughout, and, moreover, if the light by which the impression is to be made be made to fall upon the printing frame from one direction only, there will not be any loss of sharpness. A full exposure, with proper development, will ensure every detail in the one to be seen in the other. Too great intensity or contrast between the lights and shadows is to be avoided. We have now got a transparency as sharp as the negative, having all its detail and also all its distortion.

Now, by means of the camera, and with a single lens, preferably of shorter focus than that originally employed, having its stop next to the sensitive plate, make a negative from the transparency. As the negative thus obtained is distorted as regards the exact reproduction of the transparency, and as that distortion is of the opposite character, the result will be that the lines which were curved in the original negative are straight in the reproduced one. To ensure sharpness the diaphragm must be a very small one, any remaining traces of curvature, should such be perceived on the ground glass, being removed by placing the stop nearer to or farther from the lens, for the more the margin of the lens is brought into requisition the greater is its power of producing or, in this case, correcting distortion.

The Distortion of Convergence.—Every one knows that if a camera be pointed upwards at a building, so as to get its upper part into the picture, the perpendiculars will converge, being narrower at the top than at the

bottom. Every one also knows that this convergence of the perpendiculars may be altogether prevented by swinging the back of the camera so as to cause the ground glass to stand in a vertical position. It is not here a question of this or that lens, for no lens has been, or can be, made by which such convergence will not result if the sensitive plate be not vertical. All the best cameras are now provided with a swing-back, but in those of the hand or detective class it is seldom, if ever, to be found.

Let us suppose, then, that we have got a negative of a tall building, in which, from tilting up the camera without having brought the ground glass or sensitive plate into the vertical position, the sides converge and lean towards each other. How is this to be cured, or, more correctly, how is another negative to be produced from it in which no details shall be lost, but in which the converging building shall be restored to its original perpendicular position?

First of all, make from it a transparency by superposition in a printing frame, as before, and, having erected this transparency in front of a plate of opal glass (by preference), and, by means of a camera fitted with a short-focus, non-distorting lens, and a swing-back, focus as sharply as possible with the largest aperture, and swing back the ground glass until the convergence of the building is seen to be neutralised, and the vertical lines rendered parallel. Now insert the smallest stop, so as to ensure top and bottom being equally sharp, and expose. The negative which results from this treatment

will be rectilinear, and in every respect perfect so far as drawing is concerned.

The Distortion of Curvature and Convergence Combined.—This compound distortion is one of an intensely offensive nature. In it not only are the marginal straight lines curved, but they also converge. It is produced in its most perfect degree by having a camera without a swing-back fitted with a wide-angle, single-landscape lens, and pointing it well upwards, to take in the upper part of an architectural subject. But, provided it only be sharply defined, it is amenable to being perfectly cured equally as in the former cases.

The treatment is precisely the same as in the case of the distortion of convergence, subject to this difference, that the lens by which the cure is to be effected must not be rectilinear, as in the former instance, but must be single, as in that necessary for curing the distortion of curvature. The swinging of the camera back ensures the converging lines being rendered vertical, while the counter distortion of the lens equally ensures their being made quite straight.

CHAPTER XXXVI.

LANTERN OPTICS—ENLARGING AND PROJECTING.

In this subject are embraced the radiant or light, the condenser, and the object-glass or projecting lens.

The Light.—This, for enlarging, must be small in dimensions and intense in quality; the former in order to obtain sharpness, the latter to obviate the necessity of giving a protracted exposure.

Mineral Oil Lamps.—These, when well selected, are extremely convenient. It is probable that on account of its smallness an Argand flame possesses greater advantages than any other. It will undoubtedly serve the purpose equally as well as the limelight, provided a diaphragm be interposed, close to the flame, to cut off the top and bottom, as magnitude of the radiant in an optical lantern conduces to impaired definition. The theoretically perfect light is one in which dimensions scarcely find a place; but its attainment being impracticable we must do the next best thing. Something much higher is aimed at in the optical requirements of enlarging than those which obtain when a luminous image is thrown upon a screen for the illustration of a lecture or the delectation of juveniles at an evening gathering. Parallax in the flame must be avoided as

much as possible, else will definition of a high class be sought for in vain.

The Marcy Lamp. The Marcy lamp is also a good one. By the Marcy lamp we mean all those in which the burner consists of more than one flat wick turned endwise to the condenser. Marcy, of Philadelphia, used two, others three, four, and five. The principle is the same. Various names are now given to this system of lighting according as it finds development in the lamps of the numerous manufacturers by whom it is issued. For projections it is powerful, and has superseded the Argand burner, but we have now to look at something else than mere power. The fact of the edges of the various flames which are contracted being axial in the optical system implies a fulfilment of the condition of sharpness in its highest form axially; but when oblique incidences are considered then are we met by magnitude of flame, and consequent parallax. Nevertheless, when the relative positions of the flames each to the other are such as to prevent vertical lines of varying luminousness being apparent in the centre, enlargements of fairly good sharpness and equal illumination throughout may be obtained by its agency.

Limelight.—One or other forms of the limelight may be employed with unvarying success. The blow-through jet is the safest and simplest when carburetted hydrogen or common house gas is used. Where this gas is not accessible then will the flame of a spirit lamp answer quite well. The blowpipe from the cylinder or bag of oxygen playing on this flame causes it to impinge upon a cylinder of

lime, which, becoming incandescent under the great heat, emits a powerful light. The most intense form of this light is when the hydrogen and oxygen, both under high pressure, are brought into mixture just before they issue from the orifice of the burner. The light, when the gases are properly regulated, is not large, but exceedingly intense.

Albo-Carbon.—A flame of common gas enriched by 'albo-carbon,' or any other suitable hydro-carbon, has in our hands as well as in those of others proved to be a very suitable light for enlargements. Its best form is that which we introduced at the 1887 Conference of the Camera Club, and consists of two fishtail burners, separated from each other by the extent of an inch, both flames having their flat sides towards the condenser, there being an opaque disc, with a circular aperture in it of a little over half an inch in diameter, placed as close as possible up against the foremost flame so as to reduce its effective area. The position of this aperture must be such as to be opposite to the most luminous part of the flame. The second flame behind the anterior one serves to confer intensity, and is of great utility; but nothing seems to be gained by a third burner. The gas flame, when thus enriched by the vapours of the albo-carbon, becomes very intense. An Argand flame from gas thus enriched ought to yield a light of great excellence, provided it has a smaller flame ascending through its centre, and that provision is made to condense it by diminishing its diameter either by a brass solar cap to cause a strong air current to impinge upon the flame a little above the burner, or by a contraction in the glass

chimney. Whiteness and intensity in such a case are increased by a judicious lengthening of the chimney to increase the draught. The area of the flame must, however, be reduced by the expedient already pointed out.

The Condenser.—The use of a condenser is to gather together rays from the lamp which would otherwise be

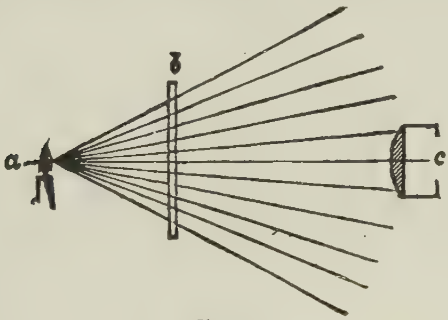

Fig. 61.

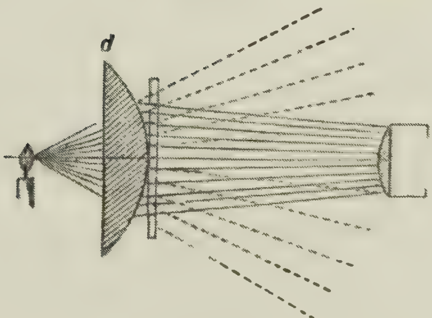

Fig. 62.

lost, and bend them in such a way as to pass through the negative and on towards the objective. Let *a*

(Fig. 61) be the radiant, *b* the negative, and *c* the objective. Notice that while the rays are transmitted through the negative only those that are nearly central or axial reach the objective. Observe now what takes place when a lens intercepts the rays ere they reach the negative. They are refracted, and instead of getting lost as before (as shown by the diverging dotted lines), they have become deflected in the direction of the objective, and were the eye placed at the diaphragm of this objective it would see every part of the negative brightly illuminated. One condenser, however, does not answer properly on account of the spherical aberration that arises when the focus is short, as it must necessarily be.

The condensers most commonly employed in optical lanterns consist of two plano-convex lenses mounted

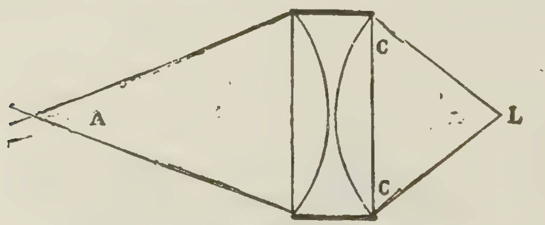

Fig. 63.

close together, the convex surfaces towards each other, as shown in Fig. 63, in which L is the light, C the condensers, and A the apex of the projected luminous cone. This form answers fairly well when the flame is large, but, unless made with a long focus, it will not perform in a satisfactory manner when the flame or radiant is

small. A better form, if only two lenses must be employed, is to have a plano-convex, or a lens of slightly meniscus form (this being according to the nature of the glass employed) working in conjunction with a bi-convex lens (Fig. 64). When the curvatures are such that the rays after transmission through the former of these fall upon the latter in a parallel direction, then must the curves of the latter not be of equal radius, but such as to make it a 'crossed lens,' in which the radii are as one to six, or nearly so, this being well known to be a form that is fairly conducive to the reduction of spherical aberration. But even here, unless the focus of this combination be long, perfection of illumination is unattainable. Why, then, not make it long? For this reason, that the loss of light would be too serious. It is of primary importance that the light in a lantern, whether for projecting a picture for examination or for enlarging, be powerful. How is this to be done? We answer it by requesting attention to the preceding diagram, in which, although the lenses are not so correctly figured as they ought to be, the principle is plainly enough shown. In this diagram an angle of illumination, say of ninety degrees, might be obtained, but the condensers are unable to grasp more than *c* and *d*,

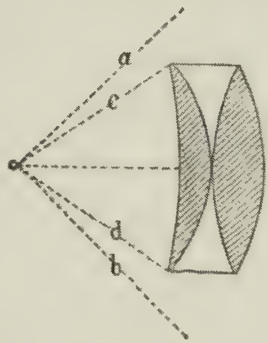

Fig. 64.

and even a little less than this, the large volume from *a* to *c* and from *b* to *d* being left outstanding. Now when it is considered that this represents a loss of about one-half of the light, its reclamation is evidently worthy of attempting. By intercepting these lost rays by a plano-convex or a meniscus lens, which need not be of so great a diameter as the others, they are by it secured and made to impinge. The deduction from this is that a triple condenser is better than a double one.

The best form of a double condenser is that shown in Fig. 65, which consists of a plano-convex and a

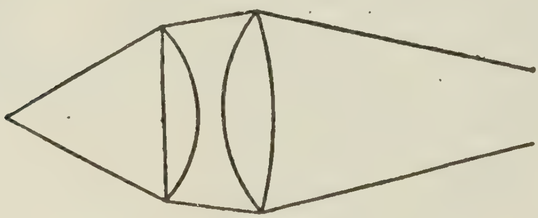

Fig. 65.

crossed lens, the flat side of the former being next to the light. It does not, however, include such a wide angle as those of triple form, although when well made its spherical aberration is but small.

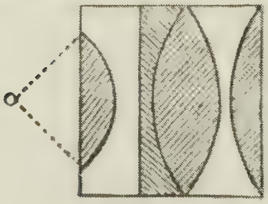

Fig. 66.

Triple Condensers.—One of this class which we devised many years ago, was composed of three plano-convex lenses (Fig. 66), the centre one of which was achromatised, and that farthest

from the light of colourless crown of a high refractive index. This gave excellent illumination, but is expensive to construct.

The achromatic condenser of Thomas Grubb, figured below (Fig. 67), in which A is a piece of plain glass to act as a protection to the condensers; B is a plano-convex simple lens; C a plano-convex achromatised; and D a combination very much over-corrected

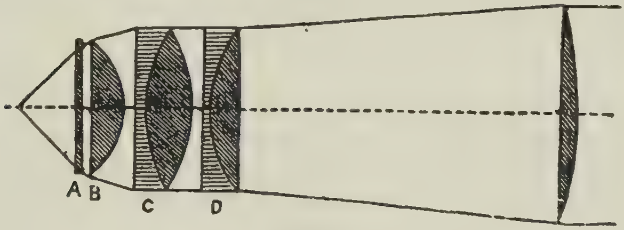

Fig. 67.

for colour, and of slight negative power, although the externals are plane. From C to D the rays are nearly parallel. Passing through D, they diverge until they are received by a large lens by which they are rendered convergent.

Achromatic Condensers.—Although we have just described two achromatic condensers, we do not consider that these are necessary for lantern work. Chromatic aberration is reduced to some extent by the behaviour of a ray which, when it passes through the first lens (unduly separated from the second for the sake of illustration), is decomposed as shown at *r* and *b* in the figure (68), the second lens having a tendency to bring

these coloured rays together again. For this reason the compound condenser was formerly designated as achromatic.

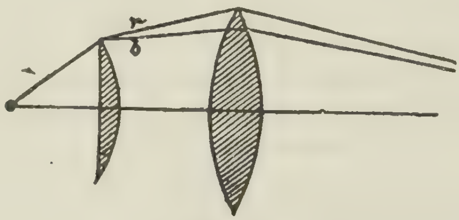

Fig. 68.

Wide-Angle Triple Condensers.—When lecturing before the Camera Club on the principles which underlay the construction of a condenser that would transmit a larger amount of light than was usual, and assuming the lime-light to be the source of illumination, we inquired the greatest angle of light possible to be got advantageously through a condensing system, as this lay at the root of the whole matter, and in doing so had to ascertain how near can the light be approximated to the first surface with safety. From innumerable trials with lenses of a thickness not too great, and set with such a degree of looseness in the brass-work as not to be cell-bound, we find that two inches may be considered as quite safe. When condensers crack, it is usually the result of their being too tightly burnished in their cells, brought too suddenly under the influence of the heat of the radiant, or being subjected to currents of cold air. We assume, of course, the perfect annealing of the glass of which they are formed.

Functions of the Condenser.—At this stage we proceed to analyse the functions of a lantern condenser, so-called. We find that these are (1) the collecting and (2) the condensing of the light. Of these, the former is much the more important. What we wish done is the collection of so many rays as to form a large angle, and their projection forward in as near an approach to parallelism as possible. Absolute parallelism cannot be obtained unless the flame were a point, instead of being, as it is, a disc or patch having sensible dimensions of, say, a quarter of an inch upwards.

Some of the cheap French condensers (of which we would not speak disparagingly, for they render excellent service, and are marvels at their price) transmit an angle of light of from 40° to 50°, and a superior class of London-made articles claims to embrace 60°. But, by a slightly increased expenditure of optical means, it is possible to increase this angle to 95°, which somewhat more than doubles the intensity of the illumination. Let us see in what way this is to be accomplished,

Kepler's law is that the focus of a plano-convex lens equals the diameter of the sphere of convexity. This is, of course, for parallel rays, and it is those we are dealing with at present; and we are also dealing with plano-convex lenses, these being the best for condensers, subject, perhaps, to a slight hollowing of the flat surface. Well, it is very evident that, if we desire a large angle of light, the single Kepler won't do much for us, unless, indeed, it were made enormously thick—even hemispherical—when we would encounter two evils. First,

the enormous spherical aberration consequent upon transmitting light through a bull's-eye, and, secondly, the proximity of the said bull's-eye to the radiant, which not only emits light but heat—a heat which would quickly cause our bull's-eye to be fractured. How, then, is it to be accomplished? By borrowing the ideas of the microscopist. Who ever heard of a microscopic objective of even the most distant pretensions to wide angle being composed of one lens? Well, no more is it possible in our collecting system, which is analogous.

Collecting System.—We must have, at least, two lenses for our purpose. One of them—that nearest to the light—must be 4½ inches in diameter in order to catch up the 95° spoken of. But this cannot render the rays parallel; still, it transmits them to its colleague under such circumstances that *it* does so, the two lenses thus doing what no one singly could effect. The first lens of the collecting system is comparatively thin, which, apart from any optical advantage, is useful in this respect, that it has to bear the first impact of the heat, and this lessens the liability to fracture. It is only sixteen mm. (⅝ inch) thick in the centre, is eight to nine inches focus, and is formed by preference of flint glass. The second element is five inches in diameter, and, the radius of curvature being rather shorter, this, combined with its greater diameter, causes it to be proportionally thicker, being twenty-eight mm. ($1\frac{1}{16}$ inch) at its centre, and seven inches focus. This lens, too, should be made of colourless glass. The loss of light from absorption is trivial, and that from oblique incidence is really so little as to be unworthy of

notice, but it carries with it its compensation, for it occurs most at the thinnest portions of the lens, where there is the least absorption, and thus aids in ensuring uniformity of illumination throughout the entire beam. But it may be reduced by rendering the first surface *concave* instead of plane, and retaining the balance of power by grinding the back surface on a tool of shorter radius. At one time we were much in love with the meniscus form of lens for this purpose, but, after many trials with lenses both plano, meniscus, and plano-convex, and formed of different kinds of glass, from St. Gobain's crown to English flint, we arrived at the conclusion that the plane surface answered every purpose.

If the radiant were infinitesimally small, a parallel beam of a large collected angle could be transmitted with a singular degree of perfection for several yards. With a triple collecting system (that worked out by Dr. Charles Cresson, in which the first lens is a plano-convex 4½ inches radius, the second a meniscus, respectively 30 inches and 6 inches; and the third a crossed lens of 52 inches and 8¾ inches radii) we projected a very tiny gaslight on to the dial of a French clock several yards distant, which was thus illuminated a whole season. But such extreme nicety is not required in the practical working of the optical lantern, as, owing to the magnitude of the flame, two elements answer every purpose. The two described should be mounted together as closely as possible, fixed permanently in the lantern, and must always be used together, and not separate. Until a compound collecting system of this nature is tried, one

can form no idea of the capabilities of the lantern for certain scientific purposes, such as polarising.

Condensing System.—We now direct attention to the *condensing* element of this optical system. We have seen that the two elements of the collecting portion must be fixed and inseparable. This, on the contrary, should be variable, and selected to suit the special end in view. Its form may be plano-convex, more especially if for use with long-focus objectives; but if the latter is to be short-focus, and the condenser of crown glass, then is the crossed form, in which the curves are as one to six or two to thirteen, open to be preferred.

But dealing, as we now are, with immergent parallel rays, it were folly to imagine that a condenser properly adapted for an objective of 12 inches focus will answer equally well for one of 6 inches. Bearing in mind Kepler's law, which, however, applies only to one kind of glass, and must not be held as applicable equally to the flint glasses, especially those of the denser sort procurable at the present day, we would say that for long-projection lenses of 12 to 15-inch focus a plano-convex having a radius of curvature of 7 inches will serve every purpose; for an objective of 8 to 10 inches the radius may be 4½ inches, while for one of 6 to 8 inches 4 inches will suffice. But, as we have said, this latter may with advantage be a crossed lens, in which case the radius of the more convex side will be longer.

The Lantern Objective.—The requirements of the lantern objective are that it shall receive and transmit all the light that passes through the condensers, and

that it shall give a flat field with good definition throughout. Its diameter, especially that of its posterior combination, must be sufficiently large to take in not merely the whole of the cone of rays emerging from the condenser, but by preference a little more. This permits of the utilisation of a small portion of light radiated from the substance of the image itself.

A large back lens also permits it to be brought nearer to the picture, and this is advantageous, especially with the condensers of the common order, as it acts in condensing the scattered rays from those of this class, enabling also the light to be approached nearer to the condenser. The lens tube should be longer than in the case of its application to photography, for, unlike this, all it is required to cover is the very limited area comprised in a plate three and a quarter inches square, minus the portion occupied by the mat. For the highest class of objective, it suffices that it be achromatic in the sense different from actinic, for, so long as the visual image is perfect, it matters not what becomes of the violet or chemical rays, or what relations they have to the luminous ones.

It is in the construction of a lantern objective of short focus that the skill of the optician is taxed, as it has to cover sharply to the margin with its full aperture, and under circumstances in which the slightest inequality in the definition is instantly detected. To a cultivated eye it is extremely unpleasant to see an image quite sharp in the centre of the disc, and falling off rapidly towards the margin, or by racking in securing marginal

sharpness at the expense of the centre. Of the various forms of objective to be met with, at any rate for those of medium short focus, we incline to give preference to that introduced ten or twelve years ago by J. H. Dallmeyer, judging by a comparison of the performance of one of this class, with several others in our possession. In it the mount is longer and the elements of the back lens (see Fig. 39, page 78) are separated to an extent which would prove fatal to sharpness in the case of one employed in producing a photographic image in the camera. If photographic lenses are to be employed in the lantern, those of the *carte-de-visite* (Petzval form), that is, those corrected for flatness of field, even to the extent of there being slight astigmatism, are advantageous. One of the most satisfactory *short*-focus objectives we ever used had a back lens two and a quarter inches in diameter, the front lens being one and three-quarter inches. We gave a very great excess of negative spherical aberration to the back lens, and the front was a nearly plano-convex achromatic of short focus. This gave a field which was singularly flat, the definition at the margin quite equalling that in the centre; but, owing to the excess of aberration spoken of, the image did not quite equal in sharpness that obtained by the ordinary *carte-de-visite* lens with rounder field. Still, spectators seated at a distance of five yards from the screen were unable readily to appreciate that the definition was imperfect, for, as is well-known, even the crude brushwork of the scene-painter seems sharp when viewed from a distance.

For objectives of long focus there does not appear to be the same tax on the skill of the optician. Poor, indeed, must be the lens of ten, twelve, or fourteen inches focus that will not cover sharply and uniformly a plate three inches in dimensions.

In the foregoing, double combinations of lenses are implied, but single achromatic lenses of plano-convex or slightly meniscus form also answer as objectives. Whether they are used singly or two placed close together, their convex sides must be next the slide, and a diaphragm must be placed outside.

The Lantern Polariscope.—With respect to polarisation of light by the lantern, the method which we described at the Nottingham meeting of the British Association fulfils the requirements of giving, with the usual lantern, a much more intense volume of polarised light than is otherwise obtainable.

Without going into too great detail, it may suffice to say that when the cone of light from the condenser is made to fall upon the bundle of glass plates by which it is polarised, only a portion of the light is thus affected, for as the angle of polarisation is an exact one, none but the axial rays are polarised in a perfect manner, all the others impinging upon the plates at other than the polarising angle. The expedient we adopt is to receive the cone upon a concave lens, by which the cone is transformed into a cylindrical bundle of rays, every one of which becomes amenable to the polarising influence of the plates, and after undergoing the change they are brought into a state of convergence by means of a convex lens.

This system applies equally to the analyser or Nicol prism, as to the polariser; in either case a considerable gain in the light accrues.

In certain scientific institutions in America, where lantern condensers have some pretensions to be called perfect, the polarising of a large volume of light is effected in a simple and most excellent manner. By means of the two collecting lenses previously described, the light from the lime is reduced to a large parallel beam, which falls upon a bundle of glass plates placed at the usual polarising angle of 56°, and after reflection is received by another lens of the same diameter, by which it is condensed. This lens is of either long or short focus, to suit its special requirement.

Such a world of wonder and beauty is opened up by the polarising attachment to the lantern, that it is matter of surprise it is not more common than it is. To polarise the light, all that is necessary is to take a packet of eight or ten clean and rather thin quarter-plate size glass plates of the best quality, and having bound them all tightly together by the edges, place them in front of the condenser, at a little distance from it, and at an angle of fifty-six degrees. With the light reflected from this parcel of plates, all the phenomena incident to polarised light may be obtained.

CHAPTER XXXVII.

PHOTO-TELESCOPIC LENSES.

BY telescopic effects is here understood the production of an image necessitating, under ordinary conditions, either a telescope of moderate dimensions having its systems of eye-pieces to magnify the aerial image, or an objective of unusually long focus. What is required is a combination that magnifies in itself while permitting the employment of a camera of no unusual length.

A telescope of the ordinary kind, having its eye-piece *in situ*, gives an image the size of which depends upon the dimensions of the telescope and the distance of the ground glass from the eye-piece. This image, however, is only sharp visually, and the adjustment for photography necessitates a number of trials in order to ascertain the position of the chemical focus. Dr. Dick, in his *Practical Astronomer* (1845), describes how the telescope may be used for throwing an image of the sun up to thirty inches in diameter upon a screen in a camera obscura consisting of the room in which the spectators are seated. This was for the purpose of exhibiting the solar spots to a number of persons at a time.

In 1870 we published a simple way of obtaining a sharp telescopic view of the sun or other distant object.

An aerial image is formed by a lens corrected for photography, and this is magnified by a similar lens of short focus placed the requisite distance in front of the aerial image. It is simple and answers well.

In the chapter on the orthoscopic lens (page 60), we have spoken of the property possessed by it of giving a larger image in a given extent of camera than that obtainable by any other objective, and it is also known to many that a greatly enlarged view of a scene can be obtained by employing an ordinary opera glass as the objective, the large lens to the outside of course. We long ago used one of the barrels of a 'twelve-lens' opera glass, that is, one in which each lens was achromatised by being formed of three elements; but felt dissatisfied on account of the very small field covered. What was covered, however, showed an image of greatly enlarged dimensions.

Dallmeyer's Teleo-Photo Objective.—It is gratifying to find that the optician named has been directing his attention to the Galilean method of forming an image, so as to adapt it for photographic purposes. The image by the outer or object-glass, which may be either a plano-convex or a crossed achromatic, is, previous to arriving at its focus, intercepted by an actinically corrected negative lens of greater negative power than the positive power of the other. This negative lens is formed of two or three elements, but the field capable of being sharply covered is limited. The degree of enlargement obtainable is determined by the separation of the lenses, coupled with the distance of the focussing screens.

CHAPTER XXXVIII.

EXCEPTIONAL RAPIDITY WITH HIGH DEFINITION.

Piazzi Smyth's Corrector.—We have previously pointed out that when a portrait combination is corrected for flatness of field, this is attainable at the expense of marginal astigmatism, unless the field to be covered be very narrow. One on the contrary that is corrected to give the best definition at the margin does so at the expense of roundness of field, so that when the centre is in focus the sides are out, and *vice versa.*

When C. Piazzi Smyth was Astronomer Royal for Scotland, he, knowing well the highest requirements of a photographic lens, devised an ingenious means by which the oblique pencils of a round field lens could be so lengthened as to eventually render the whole field flat.

The corrector employed for this purpose consists of a rather thick plate of glass the size of the sensitive plate, one side, that towards the front, being ground to a hollow or concave curve, the other side being flat. This must be mounted in front of and as close to the sensitive plate as possible.

The action of the corrector is as follows:—The axial rays from the lens fall upon its centre, where it is very

thin, and although the convergence is affected, it is only so in a slight degree, and the rays come to a focus upon the plane of representation. But at the margin the rays have to pass through a considerable body of glass, which they do in a degree more nearly approaching parallelism than previous to their entrance, and upon emerging from the flat surface they have still to travel a little farther before being brought to a focus on the sensitive plate.

As the curved surface of the corrector stands so nearly normal to the rays there is scarcely any loss from oblique incidence, while there is a very decided gain in rapidity in consequence of the large aperture that can be given to the lens.

CHAPTER XXXIX.

MISCELLANEOUS.

To Remove Lacquer from Mounts.—By immersing the brass work in boiling water in which washing soda or potash is dissolved, the lacquer will be immediately removed.

A better way, and one by which the necessity for heating is obviated, consists in applying, by means of a tuft of cotton wool, a mixture of equal parts of alcohol and ammonia.

Lacquering. — Ordinary lacquering necessitates the heating of the mount in order to its close adhesion, and not drying with a chilled surface. But if the lacquer be rendered alkaline by the addition of a small proportion of ammonia, it will dry bright without heat. This applies in a special manner to lacquers of which shellac forms the main constituent.

An excellent tough transparent coating for brass is obtained by coating it cold with a solution of celluloid in acetate of amyl (or acetone). It takes several hours to become quite dry, but is then hard and durable.

Staining Brass Black.—This system consists in staining the surface of the metal in contradistinction to applying an opaque black varnish.

A black which penetrates the surface well, consists

in immersing the article, previously made clean and freed from greasiness, in a weak solution of a mixture of the nitrates of copper and silver, and then exposing to heat till the colour was well developed, afterwards plunging into water. In this mixture the copper should largely predominate.

A method of staining, without applying heat, consists in suspending the article for a short time in a solution composed of one ounce of carbonate of copper, dissolved in eight ounces of ammonia, to which is then added sixteen ounces of water. The carbonate of copper is obtained by dissolving sulphate of copper in water, and carbonate of potash in another quantity of water, and pouring one into the other. Decomposition immediately takes place, the carbonate of copper being precipated. Pour off the supernatant liquid and wash in two or three changes of water.

Staining Brass various Colours.—Although the author cannot conceive of lens fittings being stained other than black, yet such a variety of really beautiful colours was obtained by the following process before the brass took on a black stain, that it may be well to record it. Every photographer knows that a solution of hyposulphite of soda is immediately decomposed by the addition of a variety of salts and by acids. Dissolve three-quarters of an ounce of hyposulphite in a half-pint of water, and in another half-pint of water dissolve three-quarters of an ounce of acetate of lead. Mix the two solutions and warm them, then at once immerse the articles to be coloured.

Instead of the acetate of lead we have employed sulphuric acid in very small quantity to effect the decomposition of the hyposulphite. Scarcely a colour can be named which the brass (which must be scrupulously clean) will not assume in successive stages of the immersion.

Some stain brass to a good black colour by brushing it with a dilute solution of nitrate of mercury, followed by two or more applications of a solution of sulphide of potassium (liver of sulphur).

Dead Black Varnish.—This may be made in several ways, among others by stirring lamp black intimately with a rather thin Brunswick black, the quantity of the former being such as to ensure its drying with a dead surface.

The best opticians employ a mixture of vegetable black and lacquer, the proportions being determined by trial. The quantity of black must be just such as to cause it to dry dead and no more. A good way of mixing them is to place an ounce of ordinary gun-shot with it in the bottle, and shake well up. The article must be heated ere this varnish is applied.

One of the toughest dead black varnishes we have ever tried is obtained from importers of American lacquers. It is sold under the name of enameloid, and, so far as we can see, is composed of celluloid dissolved in acetone, with the requisite quantity of vegetable or other black added to ensure deadness. It is applied cold, and dries in one or two hours.

Focussing Screen for Lens Testing.—If an extremely

fine grey glass surface be required for receiving a small and delicate image, as in testing lenses or for photo-microscopic focussing, the ground glass obtained in commerce may not unfrequently be found to be too coarse. A very fine grain can be obtained by exposing a sheet of scrupulously cleaned patent plate to the fumes of fluoric acid generated in the following manner:—Having obtained a moderately deep vessel formed of sheet lead, gutta percha, or vulcanite, sprinkle the bottom with some finely crushed fluor spar, and over this pour a little sulphuric acid. Acid fumes will be immediately generated, and by allowing them to act upon the surface of the glass this becomes corroded, the grain at first being exceedingly fine and yet capable of arresting an image thrown upon it by a lens.

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